UNCLASSIFIED

AD NUMBER
AD880991
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Administrative/Operational Use; NOV 1970. Other requests shall be referred to Office of Naval Research, Washington, DC 20360.**
AUTHORITY
ONR ltr 8 Oct 1975

THIS PAGE IS UNCLASSIFIED

UILU-ENG-71-2539

GENERALIZED DIGITAL SIMULATION OF A CDAA DIRECTION FINDING SYSTEM

by
EDWARD W. ERNST
R. E. HUNNINGHAUS

RRL PUBLICATION NO. 382

November 1970

Technical Report No. 21
Contract N00014-67-A-0305-0002

Supported by
Office of Naval Research
and the
Naval Electronics Systems Command

RADIOLOCATION RESEARCH LABORATORY
DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS 61801

GENERALIZED DIGITAL SIMULATION OF A CDAA DIRECTION FINDING SYSTEM

by

Edward W. Ernst

R. E. Hunninghaus

RRL Publication No. 382

November 1970

Technical Report No. 21

Contract N00014-67-A-0305-0002

Supported by:

Office of Naval Research

Radiolocation Research Laboratory
Department of Electrical Engineering
Engineering Experiment Station
University of Illinois
Urbana, Illinois

TABLE OF CONTENTS

ABSTRACT

The simulation program GCAAS (General Circular Antenna Array Simulator) has been developed to simulate the output data from a circularly disposed antenna array (CDAA)-direction finding system under known input signal conditions. The CDAA system which has been simulated is similar to the Wullenweber Direction Finding System at the University of Illinois and may consist of as many as 360 antenna elements in a circular array of any reasonable dimensions and simulates the outputs obtained from the array used in a scanning mode.

The input signal conditions may include up to five incoming signals at different azimuthal and elevation angles of arrival with time-dependent relative phase shifts between the incoming signals. The output consists of the sum, difference and differential phase data sampled at regular intervals of azimuth and stored on magnetic tape for further use in the determination of the direction of arrival. A maximum of 100 samples of the output data set may be obtained from each scan.

I. INTRODUCTION

This generalized simulator of a circularly disposed antenna array (CDAA) direction finding system has been developed to satisfy the need for a means of producing simulated system output data, under known input conditions, to be used in future studies relating to the different methods for direction of arrival calculation. As a consequence of the general nature of the simulator, it may also be used in studies related to the construction and operation of the CDAA system.

The system outputs simulated are the scanning mode sum, difference, and differential phase information; it is possible in this simulator to produce these outputs corresponding to a series of related time-dependent scans. The primary needs for this simulated data are for use in: 1) development of a difference method for direction of arrival calculation, 2) a study of the presently used sum and differential phase methods for direction of arrival calculation, and 3) a comparison of the three methods for direction of arrival calculation.

The known input conditions this simulator has been designed to handle are:

1) Single input signal.

2) Multiple input signals from the same source (wave interference).

3) Amplitude modulation of the signal.

4) Addition of random noise to the signal.

The individual signal conditions which comprise the total input signal conditions are to be specified (for each input signal) by azimuthal and elevation angle, relative amplitude, initial reference phase and a time-dependent reference phase shift.

II. THE PHYSICAL SYSTEM

The CDAA direction finding system to be simulated is similar to the Wullenweber Direction Finding System at the University of Illinois.

The array consists of a number of identical folded vertical monopole antenna elements, mounted on a ground mat, evenly spaced around the circumference of a circle. Within this circular array and concentric to it is located a vertical reflecting cylinder of a height somewhat greater than that of the antenna elements. The output of each antenna element is connected by a matched cable to a multicoupling device; each cable has the same electrical length. Each multicoupler is a wide band amplifier with a gain of unity and several outputs with the same output signal are available at each of the multicoupler outputs. (Refer to Figure 1.)

One output from each multicoupler is fed into an electro-mechanical scanner. This scanner selects a group of consecutive antenna elements to produce a number of scanning element voltages. These scanning elements have the same angular spacing as the antenna elements and are subdivided into a right and left bank, each of which has the same number of elements. Midway between the two banks is a plane of symmetry referred to as the boresight. The scanner is also set to rotate at a constant speed in the clockwise direction. Thus, the scanner is continually selecting new antenna elements to produce the scanning element voltages as the boresight moves to the right. (Note: The clockwise direction is referred to as the right and the counter-clockwise direction as the left.)

The right and left scanning elements are connected to the inputs of two identical sets of delay lines, one set for each bank. The effect of

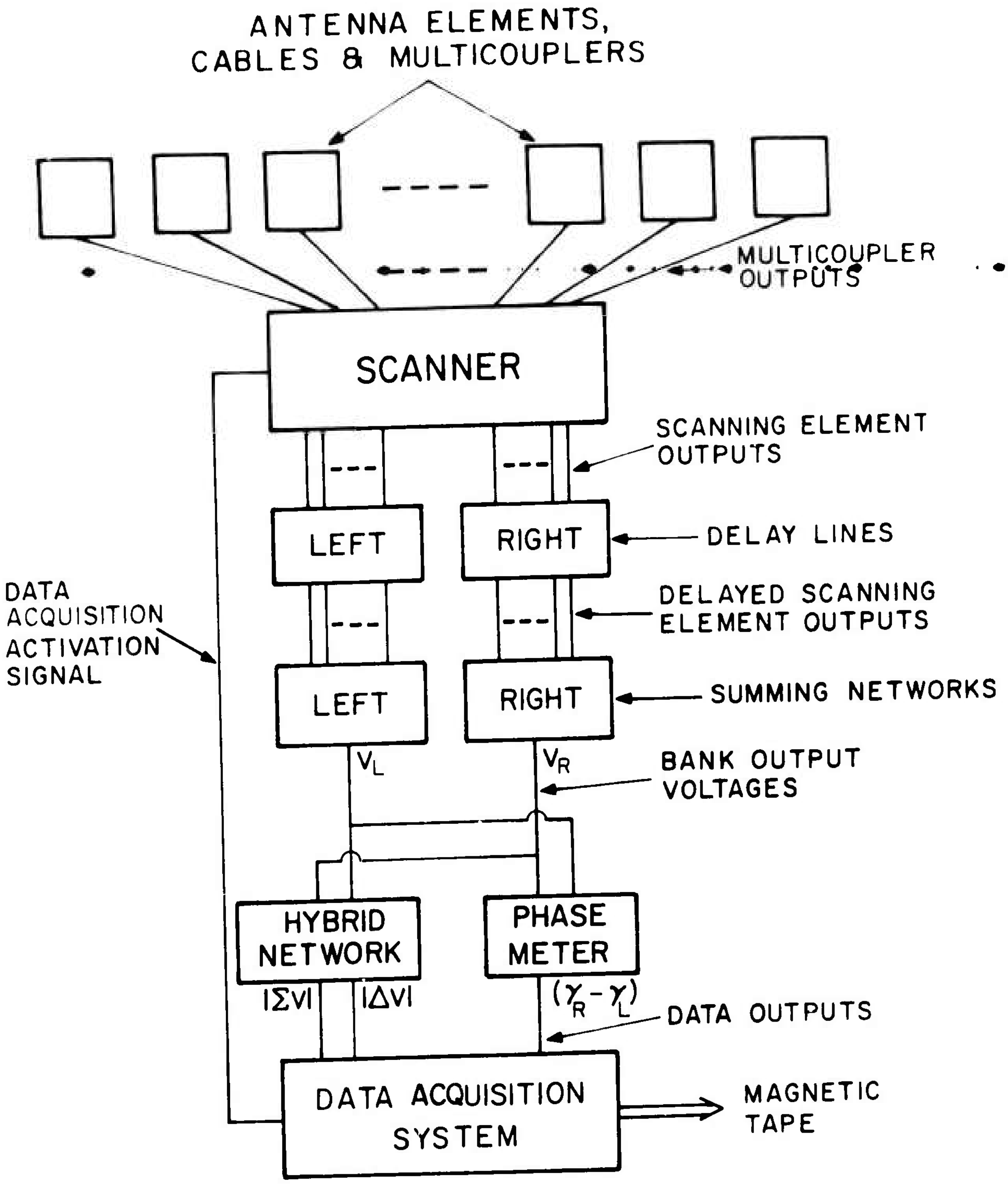


Figure 1. Block Diagram of CDAA Direction Finding System.

the addition of the delay lines is to make the delayed scanning element voltages, for an incoming signal arriving at a particular elevation angle of arrival known as the cophasal angle, appear to be the same as the element voltages that would be received from a linear array of vertical antenna elements rotating about a vertical axis at the center of the array.

The outputs of the delay lines are tied to identical summing networks, one for each bank. These summing networks perform the phasor addition of the delayed scanning element voltages that are the inputs to the network. The outputs of the summing networks are the right and left bank voltages.

It is from these two bank voltages that the system outputs are obtained. Feeding the bank voltages into the hybrid network, the sum and difference voltages are obtained; feeding the bank voltages into the phase meter yields the differential phase data.

The system produces continuous analog data, but for acquisition and storage of the data in a digital format the data must be in a discretely sampled format. The data acquisition system[1] performs the necessary sampling and analog-to-digital conversion to put the output in a format suitable for tape storage.

The data acquisition system is activated by the position of the scanner boresight. Once the acquisition system is activated, the sum, difference, and differential phase data are sampled and converted from voltage level to digital representations and stored on magnetic tape. The activation settings in the scanner are such that a given number of sample points per scan is taken with equal angular intervals between the boresight positions for consecutive sample points. The entire angular interval over which the sample points are taken is referred to as the

sampling window. The window is always less than 90° and the center of the window has been designated the sector center.

It is from a later analysis of the information stored on the magnetic tape that the direction of arrival is calculated.

III. MATHEMATICAL MODEL OF THE SYSTEM

The model of the CDAA consists of NOA antenna elements located outside a reflecting cylinder of radius A with the distance from the antenna element to the reflecting cylinder surface equal to D.

In the model, an antenna element, cable, and multicoupler are considered one unit. Since all of the cables are of the same electrical length and the gain of each multicoupler is unity, the outputs of the multicouplers are taken to be the same as the outputs of the antenna elements to which they are connected. The phasor voltage output calculations used for the vertical folded monopole antenna elements, excited by a single signal are basically the same as those used by Jones.[2] These calculations have been expanded for multiple signals (wave interference) by the addition of a relative amplitude factor and a reference phase for each signal.

Jones' modified expressions for antenna element voltage, as modified for element i and signal w, are:

Amplitude

$$A_{iw}\ (\phi_{iw},\ \theta_w) = [\mathrm{COS}(\theta_w) * \mathrm{SIN}\ \frac{2\pi * D}{WL} * \mathrm{COS}(\phi_{iw}) * \mathrm{COS}(\theta_w)\ ] * WAMP_w \quad (1)$$

Phase

$$P_{iw}\ (\phi_{iw},\ \theta_w) = \frac{2\pi * A}{WL} * \mathrm{COS}\ (\phi_{iw}) * \mathrm{COS}\ (\theta_w) + WPHI_w \quad (2)$$

where

WL = Wavelength of the signal, calculated from the carrier frequency FREQC (in MHz) as WL = 299.8/FREQC

A = Radius of the reflecting cylinder in meters

D = Antenna element to reflecting cylinder distance in meters

ϕ_{iw} = Difference between the azimuthal angle of the antenna element i and the angle of arrival of signal w

θ_w = Elevation angle of signal w

$WAMP_w$ = Signal w relative amplitude factor

$WPHI_w$ = Signal w reference phase factor.

Figure 2 shows the geometry that relates these terms and Equations (1) and (2).

For the multiple input signal conditions the antenna element voltage, by superposition, is taken as the sum of the voltages excited by the individual signals. Since summations are more readily carried out in Cartesian coordinates rather than polar coordinates, the phasor voltages, which are excited by the individual signals, are converted from polar to Cartesian form and summed over the individual incoming signals to give the antenna element voltage. Thus for n incoming signals the complex antenna element voltage, for element i, is computed as:

$$RE_i = \sum_{w=1}^{n} [A_{iw} (\phi_{iw}, \theta_w) * COS (P_{iw} (\phi_{iw}, \theta_w))] \qquad (3)$$

$$IM_i = \sum_{w=1}^{n} [A_{iw} (\phi_{iw}, \theta_w) * SIN (P_{iw} (\phi_{iw}, \theta_w))]. \qquad (4)$$

The superposition principle is also used to add the effect of the time-dependent phase shift, for the individual signals, to the antenna element voltage. The antenna element voltage is recalculated for the Time T by adding a phase shift voltage, for each incoming signal, to the element voltage at time To. Thus for element i at time T, and n incoming signals, the element voltage is recalculated as:

$$RE_{i(T)} = RE_{i(To)} + [Aiw (\phi_{iw}, \theta_w) * (COS (PA2)-COS(PA1))] \qquad (5)$$

$$IM_{i(T)} = IM_{i(To)} + [Aiw (\phi_{iw}, \theta_w) * (SIN (PA2)-SIN (PA1))], \qquad (6)$$

where

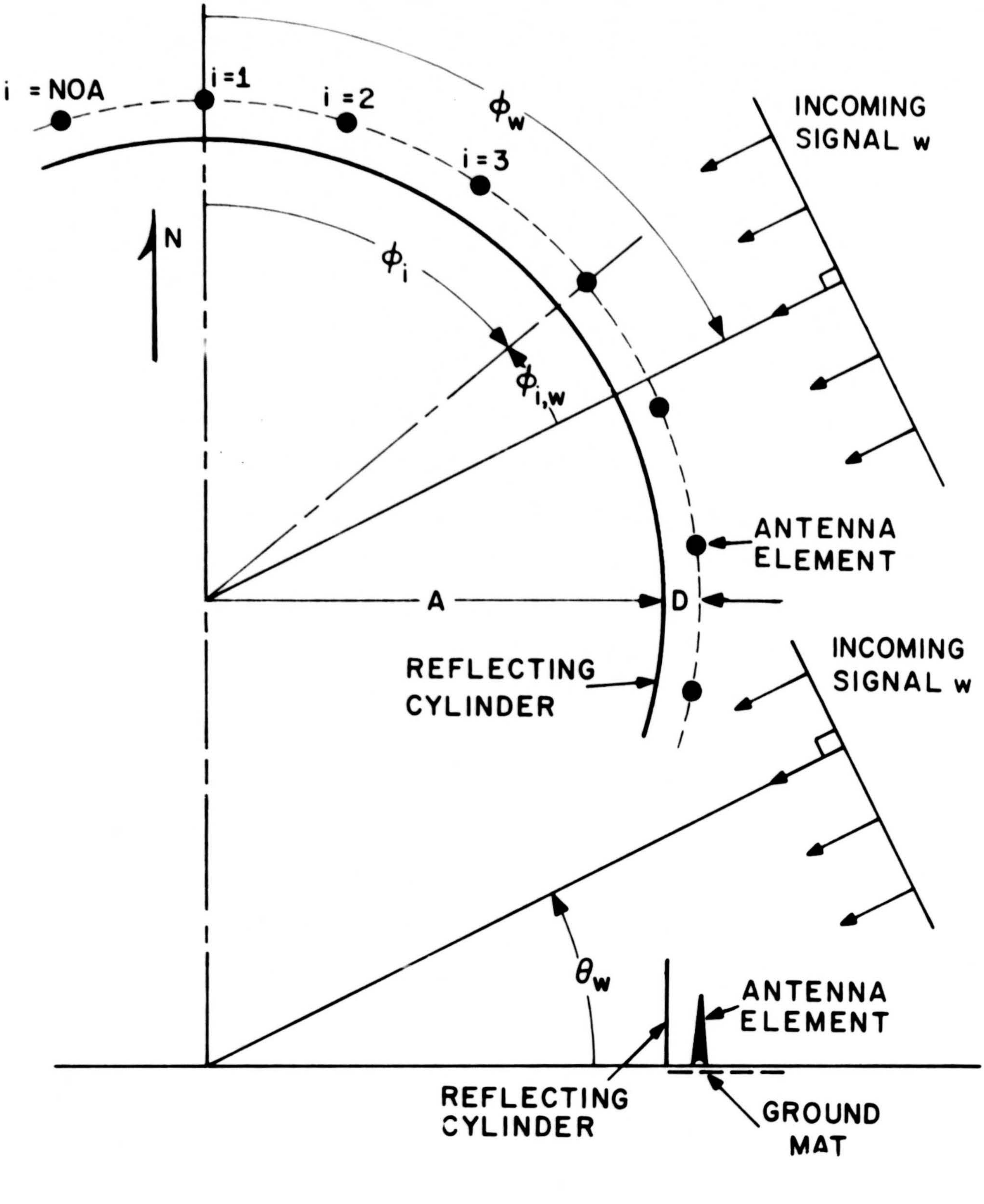


Figure 2. Antenna Array Geometry.

$PA1 = P_{iw} (\phi_{iw}, w)$ + Time Dep phase shift at To, for signal w (7)

$PA2 = P_{iw} (\phi_{iw}, w)$ + Time Dep phase shift at T, for signal w. (8)

For the calculation of the time dependent phase shift and the amplitude modulation of the incoming signals, it is necessary to compute simulated time. This simulated time has as its basis the rotation of the scanner. The scanner rotates once every SCANT seconds and if DEG is the angle of rotation of the boresight since T=0, then the simulated time T may be given by:

$$T = SCANT * (DEG/360) \quad (9)$$

Where PST_w is the amount of phase shift per scan for signal w, Equations (7) and (8) become

$$PA1 = P_{iw} (\phi_{iw}, \theta_w) + PST_w * (To/SCANT) \quad (10)$$

$$PA2 = P_{iw} (\phi_{iw}, \theta_w) + PST_w * (T/SCANT) . \quad (11)$$

The scanner consists of NAS scanning elements with NAS2 = NAS/2 elements in each bank. The scanner will be set to take ISAM sample points per scan; the interval between the boresight for consecutive sample points in the scan is SAMI. The sector center is set at SECT and the width of the sampling window will be WIDTH = (ISAM-1) * SAMI.

The scanner reactively couples the scanning elements to the antenna elements to produce the scanning element voltage. The scanner is of such a nature that its coupling can be simulated by a direct (maximum to zero) relationship with the displacement of the boresight. When the scanning elements on the rotor are aligned with the antenna elements on the stator (or in other words, the boresight is exactly midway between two antenna elements), the scanning elements will have the same voltages as the antenna elements with which they are aligned and the adjacent

antenna elements will have no effect upon the scanning element voltages. As the rotor elements move out of direct alignment with the stator elements, the scanning element voltages will be taken as the sum of the effects of the two adjacent stator element voltages. (See Figure 3.) Consider a stator element l which is to the left or aligned with the rotor element i and the stator element r which is the first stator element to the right of element l. The displacement between adjacent stator elements is ANOA = (360/NOA) and if the displacement between stator element l and rotor element i is CDEL, the scanning element voltage will be taken as:

$$SRE_i = [ARE_l * (ANOA-CDEL)/ANOA] + [ARE_r * CDEL/ANOA] \tag{12}$$

$$SIM_i = [AIM_l * (ANOA-CDEL)/ANOA] + [AIM_r * CDEL/ANOA] \quad . \tag{13}$$

Since the scanner coupling is linearly related to displacement, it is possible to have sampling intervals which may have values other than multiples of an antenna spacing interval.

In modeling the system, the addition of signal amplitude modulation and random noise signals is most effectively done at the time the scanning element voltages are calculated. The amplitude modulation is added by multipling the antenna element voltages by an amplitude factor calculated for the sample point of interest at that time, where it is considered that the sampling time is relatively short in comparison to the modulation period. The percent modulation is defined as PCAM and the modulating frequency is FREQM (in KHz). Using the simulated time T, for the sample point of interest, the amplitude modulation factor is:

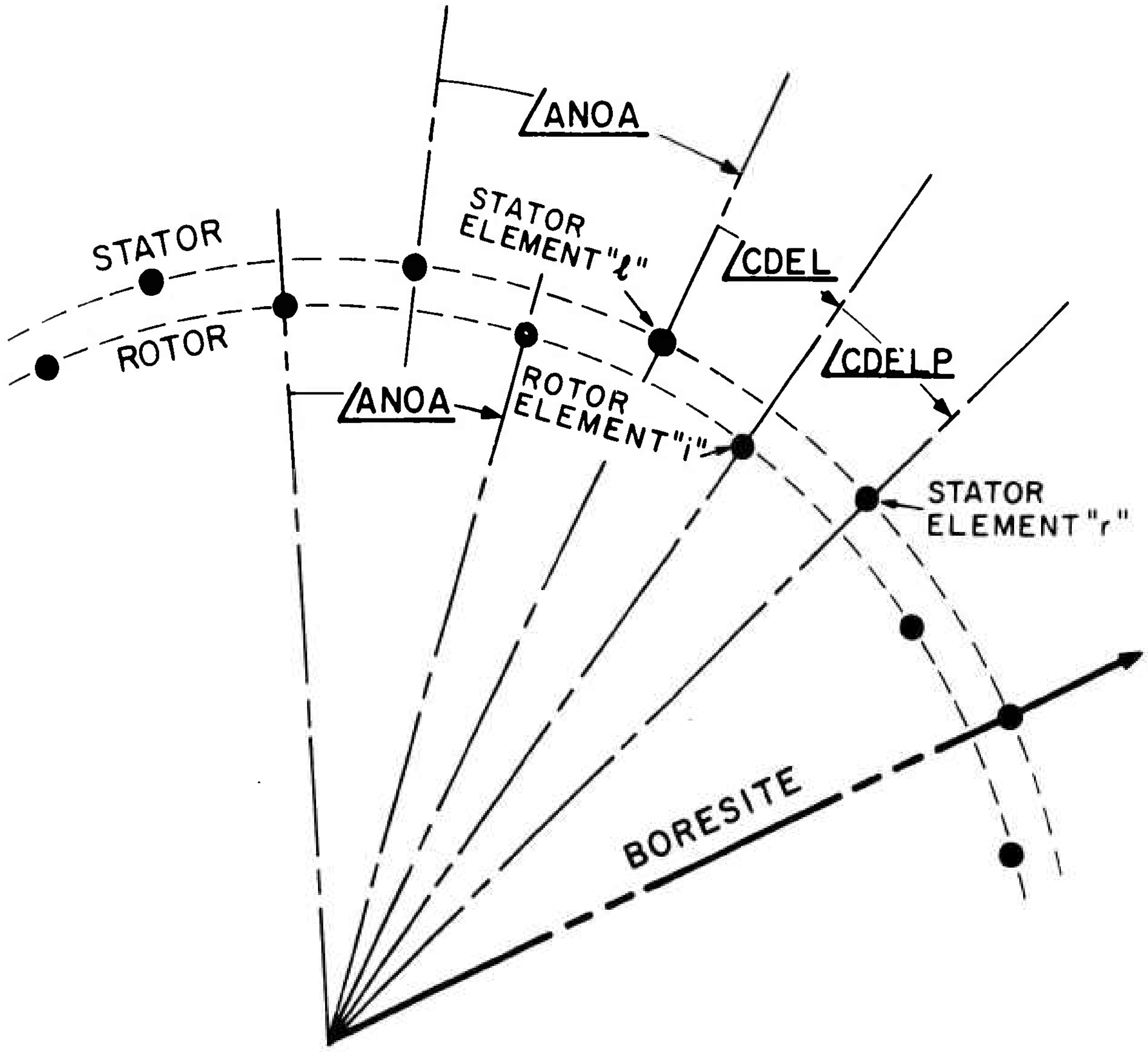


Figure 3. Scanner Geometry.

$$AMS = (1-PCAM) + PCAM * COS(2\pi * FREQM * 1000 * T). \quad (14)$$

The noise signals are produced by the use of a random number generator. The random noise voltage (ANRE, ANIM) added to the antenna element voltages when the scanning element voltage is calculated, is determined by multipling the relative noise level amplitude ANOISJ by successive real numbers supplied by a pseudo-random number generator. With the addition of amplitude modulation and random noise signals, Equations (12) and (13) become

$$SRE_i = [(AMS * ARE_l + ANRE_l) * (ANOA-CDEL)/ANOA] + [(AMS * ARE_r + ANRE_r) * CDEL/ANOA] \quad (15)$$

$$SIM_i = [(AMS * AIM_l + ANIM_l) * (ANOA-CDEL)/ANOA] + [(AMS * AIM_r + ANIM_r) * CDEL/ANOA]. \quad (16)$$

The delays which should be introduced by the phase delay lines are calculated from the antenna array geometry; for these calculations it is assumed that the scanning elements are aligned with the antenna elements around the circumference of the array. The phase delay that will be introduced for element i, which is i elements from the boresight, is directly proportional to the distance of signal propagation, along the boresight, from element i to the furthest element from the boresight, where the signal azimuthal angle of arrival is taken as the boresight setting. This distance can be realized as:

$$A * COS (CPHI) * (COS((i-1) * ANOA + ANOA2) - COS ((NAS2-1) * ANOA + ANOA2))$$

where ANOA2 = ANOA/2 and CPHI is the cophasal or assumed elevation angle of arrival. (See Figure 4.) The phase delay is then determined in radians as:

$$PDELAY_i = (2\pi * A/WL) * COS (CPHI) * (COS((i-1) * ANOA + ANOA2) - COS((NAS2-1) * ANOA + ANOA2)) . \quad (17)$$

In modeling the system it is possible to combine the addition of the phase delays to the scanning element voltages and the operation of the summing network so that the bank voltages may be calculated directly from the scanning element voltages. The phase delays are added to the scanning element complex voltages, to obtain the delayed scanning element complex voltages, as if the phase delays were a rotation of the axes in a Cartesian coordinate system. The summing network, as the name implies, produces the complex voltage for the bank by computing the complex sum of the delayed scanning element voltages. Thus the combined effect of the delay lines and the operation of the summing network will determine the bank voltage as:

$$\mathrm{SUMI} = \sum_{i=1}^{\mathrm{NAS2}} [\mathrm{SIM}_i * \mathrm{COS}\ (\mathrm{PDELAY}_i) - \mathrm{SRE}_i * \mathrm{SIN}\ (\mathrm{PDELAY}_i)] \qquad (18)$$

$$\mathrm{SUMR} = \sum_{i=1}^{\mathrm{NAS2}} [\mathrm{SIM}_i * \mathrm{SIN}\ (\mathrm{PDELAY}_i) + \mathrm{SRE}_i * \mathrm{COS}\ (\mathrm{PDELAY}_i)]\ . \qquad (19)$$

The system outputs are obtained as the outputs of the hybrid network and the phase meter with the right and left bank voltages used as the inputs.

The outputs of the hybrid network are the complex sum and difference of the bank voltages; the magnitudes of these two complex quantities are the sum and difference data outputs for the system. These two operations are carried out as:

$$\mathrm{DATAST} = \mathrm{SQRT}\ ((\mathrm{SUMR}_r + \mathrm{SUMR}_l) ** 2 + (\mathrm{SUMI}_r + \mathrm{SUMI}_l) ** 2) \qquad (20)$$

for the sum data, and

$$\mathrm{DATADT} = \mathrm{SQRT}\ ((\mathrm{SUMR}_r - \mathrm{SUMR}_l) ** 2 + (\mathrm{SUMI}_r - \mathrm{SUMI}_l) ** 2) \qquad (21)$$

for the difference data.

The differential phase measured by the phase meter provides the

differential phase data output and is computed as

$$DATP = ATAN2\,(SUMI_r,\ SUMR_r) - ATAN2(SUMI_l,\ SUMR_l) \qquad (22)$$

where ATAN2 is $\tan^{-1}$ (SUMI/SUMR) defined from -180 to +180 degrees.

In modeling the system on a digital computer the function of the data acquisition system has been simulated, as the output is already in a digital form and can be stored on magnetic tape in a digital format. It should be noted that in modeling the system the relationship between the position of the scanner boresight and the simulated time, for a given sequence of scans or sample points, is the same as the relationship between the position of boresight of the physical system and real time, for the same sequence.

IV. THE SIMULATION PROGRAM - OPERATION OF SIMULATION

The simulation program has been named GCAAS, standing for General Circular Antenna Array Simulator. A listing of this program is contained in Appendix A of this report

In an attempt to facilitate a rapid understanding of the basic operation of the Simulation Program, the program has been reduced, in Reduced Program listing number one, to the basic control statements and input operations and, in Reduced Program listings two thru eight, to the FORTRAN statements used in realizing the mathematical model of the system. These reduced program listings are contained in Appendix B of this report. All of the other program operations, which are not involved in simulation calculations, have been represented in the reduced listings as blocks.

Before explaining the operations of the program, it will be helpful to define certain variables and constants used in the program.

Reference Numbers

SETNUM is the number used to identify a given data set on the output data tape, where a data set is the output data stored on the tape for one execution of the program.

IRUN is the number used to identify a given data run, which is one of the NRUN data runs in the data set and where a data run is one simulation of a given antenna array under specified input and system operation conditions.

IWAVE is the number used to identify a given incoming signal condition, where there are NWAVE incoming signals in the data run.

IS is the number used to identify a given scan, where there are ISCAN

scans in the data run

IP is the number used to identify a given sample point, where there are ISAM sample points in each scan of the data run

IANT is the antenna element reference number, where element number one is defined as being at an azimuth of zero degrees and the reference numbers increase in the clockwise direction up to element number NOA, which is the first element to the left of element number one

IAW is the number of elements an antenna element is located away from a given incoming signal azimuthal angle of arrival. (See Figure 4).

ISE is the scanning element reference number, where element number one is the element closest to the boresight and element number NAS2 is the furthest element from the boresight.

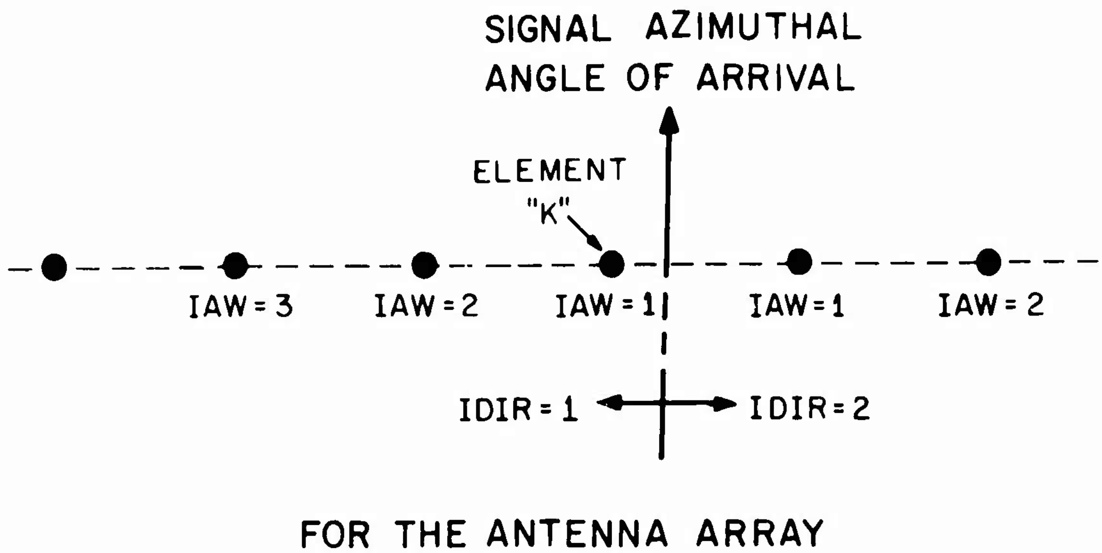
IDIR is used to specify if IAW or ISE is to the left (=1) or the right (=2) of the azimuthal angle of arrival or the boresight, respectively. It is also used to distinguish between the left (=1) and right (=2) scanning banks.

K is the reference number of the antenna element to the left of a given incoming signal azimuthal angle of arrival.

KC is the reference number of the antenna element to the left of the first scanning element in the left scanning bank for a given sample point.

IL is the reference number of the antenna element to the right of scanning element ISE for a given sample point.

IR is the reference number of the antenna element to the right of scanning element ISE for a given sample point.



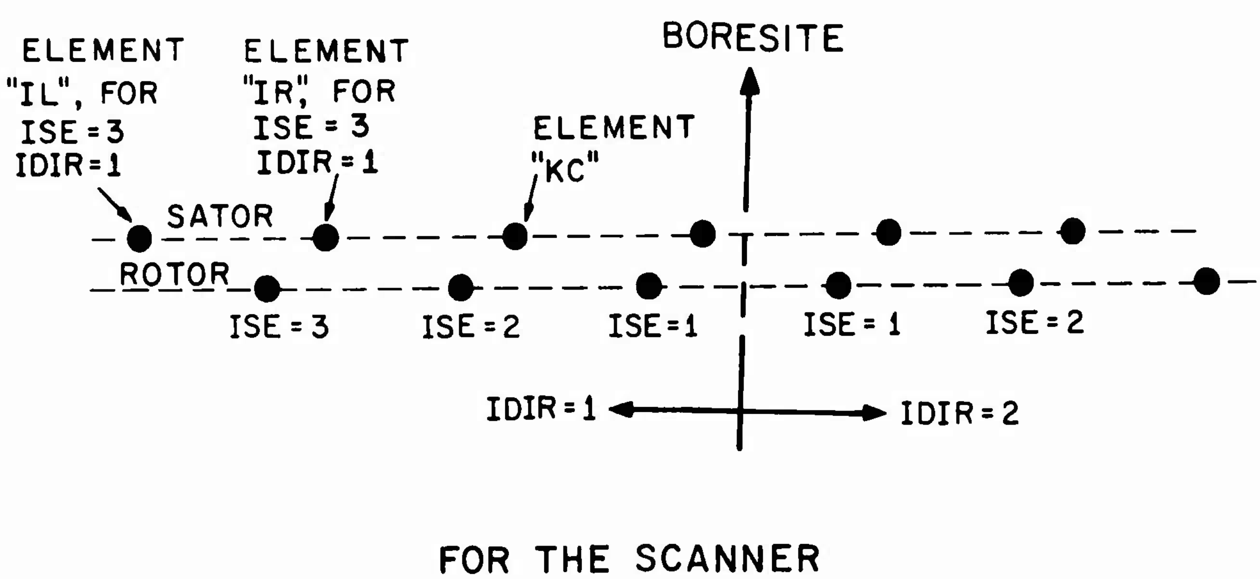


Figure 4. Reference Numbers.

Natural Constants

VEC is the velocity of propagation (=299.8 meters/microsecond).

PI is set equal to the value π (=3.14159265).

TWOPI is set equal to the value 2π.

CONRAD is the radian to degrees conversion factor (=$360/2\pi$).

Input Variables

ITAPE is the tape drive number (=1, 2, 3) on which the output data tape is mounted.

MODE specifies if a new (=1) or old (=2) output data tape is being used.

NRUN is the number of data runs in the data set.

NOA is the number of antenna elements in the array for a given data run.

A is the reflecting cylinder radius (in meters) for a given data run.

D is the reflecting cylinder to antenna element spacing (in meters) for a given data run.

NAS is the number of scanning elements for a given data run.

CPHI is the cophasal angle (in degrees) for a given data run.

NWAVE is the number of incoming signals for a given data run.

FREQC is the carrier frequency of the incoming signals (in MHz) for a given data run.

FREQM is the amplitude modulation frequency of the incoming signals (in KHz) for a given data run.

PCAM is the amplitude modulation factor for the incoming signals ($0 \le$ PCAM ≤ 1.0) for a given data run.

WAMP is the relative RMS amplitude for a given incoming signal condition.

WPHI is the reference phase (in degrees) for a given incoming signal condition.

AZM is the azimuthal angle of arrival of a given incoming signal ($0 \le$ AZM < 360 degrees).

ELEV is the elevation angle of arrival for a given incoming signal ($0 \le$ ELEV $<$ 90 degrees).

PST is the time-dependent reference phase shift per scan (in degrees) for a given incoming signal condition.

ANOIS is the relative RMS value of the noise signal.

RN is the starting number for the pseudo-random number generator. (Set RN=0 for normal operation.)

SECT is the sector center ($0 \le$ SECT $<$ 360 degrees) for a given data run.

SCANT is the time taken to make one complete scan (in seconds) for a given data run.

ISCAN is the number of scans in a given data run.

ISAM is the number of sample points in each scan for a given data run.

SAMI is the azimuthal angle between the boresight setting for two consecutive sample points in a scan (in degrees, 0 < SAMI * (ISCAN -1) < 360 degrees) for a given data run.

For the input formats of these input variables see the program forward of the simulation program GCAAS.

The Basic Operation of the Program-Reduced Program Listing Number One

The first necessary operation, after defining the natural constants (VEC, PI, TWOPI and CONRAD) and setting the data run reference number IRUN to zero, is to input the program operation variables (NRUN, ITAPE and MODE). Once ITAPE and MODE are known, then the output data tape can be properly positioned and SETNUM can be determined for the present execution of the program.

After the output tape has been positioned and SETNUM has been determined, the calculations for the first data run are begun by first incrementing the data run reference number by one, IRUN=IRUN + 1. It should be noted at the outset that the antenna array information (NOA, A, D, NAS, CPHI), the general signal information (NWAVE, FREQC, FREQM, PCAM), the noise signal information (ANOIS, RN) and the scanning operation information (SECT, SCANT, ISCAN, ISAM, SAMI) are all input once for the data run, and the incoming signal conditions (WAMP, WPHI, AZM, ELEV, PST) are input NWAVE times for the data run. It is necessary to resupply all the input information for each data run in the data set, even if certain input variables are to be the same for different data runs in the data set.

The sequence of operations for the data set, after incrementing IRUN by one is:

1) Input the antenna and general signal information.
2) Calculate the phase delays for the delay lines .
3) Input one incoming signal condition.
4) Calculate the antenna element voltages for the given signal conditions.
5) Return to 3 until the calculations for all of the incoming signal

conditions have been completed.

6) Input the noise signal and scanning operation information.

7) Define the scan number IS and initialize the simulated time for the scan.

8) Define the sample point number IP and determine the boresight setting for the sample point.

9) Increment the simulated time by the time difference between sample points and determine the amplitude modulation factor from the simulated time.

10) Perform the time-dependent phase shift calculations for the sample point.

11) Calculate the scanning bank voltages for the sample points.

12) Calculate the output data for the sample point.

13) Return to 8 until all of the calculations for all of the sample points in the scan have been completed.

14) Return to 7 until all of the calculations for all of the scans in the data run have been completed.

If IRUN $\neq$ NRUN, after the calculations for the data run have been completed increment IRUN by one and begin the calculation for the next data run. If IRUN = NRUN, the execution of the program is terminated.

During the operation of the program, for a data run, several expressions appear several times or in operations that are repeated many times; in an attempt to reduce the execution time for the program, these expressions have been reduced to constants for the data run and incoming signal conditions. The data run constants are defined as:

NOA4 = NOA/4

NAS2 = NAS/2

ANOA = 360/NOA — The spacing between array elements

ANOAP = ANOA/2 — One half the spacing between array elements

WL = VEC/FREQC — The wavelength of the incoming signals

CONST1 = TWOPI * D/WL

CONST2 = TWOPI * A/WL

CONW = TWOPI * FREQW * 1000 — The angular frequency of amplitude modulation

ANOISJ = ANOIS * .707 — The relative RMS amplitude of the real and imaginary noise signals

WIDTH = (ISAM-1) * SAMI — The width of the sampling window

SIDE = SECT - WIDTH/2 — The first boresight setting in the scan

DELT = SCANT * SAMI/360 — The time interval between two consecutive sample points.

The incoming signal constants, used in the antenna element voltage calculations, are defined as:

WPH = WPHI/CONRAD — The reference phase in radians

COSELV = COS(ELEV/CONRAD)

COSAMP = COSELV * WAMP

CONE1 = CONST1 * COSELV

CONE2 = CONST2 * COSELV .

Both the boresight settings and the simulated time are calculated for the sample point from the scan and sample point reference number. The boresight setting can be found from IP alone, since the boresight settings will always be the same for each scan in a data run. The boresight setting for sample point IP is determined as:

CENT = (IP-1) * SAMI + SIDE .

It should be noted that it may be necessary to correct CENT to lie between the limits $0 \le \text{CENT} < 360$ degrees.

The simulated time is computed by initializing the simulated time at the beginning of the scan.

T = (IS - 1) * SCANT - DELT, and then increment the simulated time by the time interval between sample points, T = T + DELT, for each sample point. It is interesting to note that this method of computation of simulated time is equivalent to:

T = (IS - 1) * SCANT + (IP - 1) * DELT.

Once the simulated time is known for the sample point, the amplitude modulation factor is determined as:

AMS = (1 - PCAM) * PCAM * COS (CONW * T)

which is Equation (14).[†]

Phase Delay Calculations- Reduced Program Listing Number Two

The first step in the phase delay calculation is to reduce redundant calculation by reducing the two terms in Equation (17), which are the same for all the scanning elements, to two constants. These two constants are defined as:

CONCHI = COS (CPHI/CONRAD) * CONST2

COSM = COS (((NAS2 - 1) * ANOA + ANOA2)/CONRAD).

Equation (17) is then implemented, for scanning element ISE, as:

PDELAY = CONCHI * (COS(((ISE - 1) * ANOA + ANOA2)/CONRAD) - COSM).

The phase delay information is then stored as:

COSP (ISE) = COS(PDELAY)

SINP (ISE) = SIN(PDELAY),

---

† Equation numbers refer to equations in Chapter 3.

since the sine and the cosine of the phase delays will be the only quantities used in further calculations.

Antenna Element Voltage Calculations-
Reduced Program Listing Number Three

After the conditions have been read and the repetitive terms used in the antenna element voltage calculation have been reduced to constants for the incoming signal IWAVE, the antenna element voltages excited by the given signal conditions are determined in the following manner:

1) Determine the element K to the left of the azimuthal angle of arrival as K = (AZM/ANOA) + 1.
2) Determine the spacing between the azimuthal angle of arrival and the first element to the left as DELK = AZM-ANOA * (K-1) and the first element to the right as DELKP = ANOA-DELK.
3) For the elements to the left of the azimuth IDIR = 1.
4) Set IAW = 1 for the first element to the left of the signal azimuth.
5) Find the proper antenna reference number as IANT = K + 1-IAW.
6) Determine the spacing between the azimuth and the element as THE = ANOA * (1-IAW)-DELK.
7) Implement Equations (1) and (2) to find the voltage excited by the signal.
8) Implement Equations (3) and (4) to find the total element complex voltage.
9) For the next element to the left IAW = IAW + 1.
10) Return to 5 if IAW ≤ NOA4.

Note that voltages will only be excited in antenna elements up to one fourth of the distance around the array from the azimuthal angle of arrival.

11) For the elements to the right of the azimuth IDIR = 2.
12) Set IAW = 1 for the first element to the right of the signal azimuth.
13) Find the proper antenna reference number as IANT = K + IAW.
14) Determine the spacing between the azimuth and the element as THE = ANOA * (IAW - 1) + DELKP.
15) Implement Equations (1) and (2) to find the voltage excited by the signal.
16) Implement Equations (3) and (4) to find the total element complex voltage.
17) For the next element to the right IAW = IAW + 1.
18) Return to 13 if IAW ≤ NOA4.

It should be noted that it may be necessary to correct IANT and THE to fit the limits 1 ≤ IANT ≤ NOA and |THE| ≤90 degrees, before being used in any calculations.

Equation (1) and (2) are implemented in the program as:

AMP = COSAMP * SIN (CONE1 * COSTHE)

and

PHI = CONE2 * COSTHE + WPH

where COSTHE is defined for the given element IANT as:

COSTHE = COS(THE/CONRAD)

and where COSAMP, CONE1, CONE2 and WPH are defined, in reduced listing number one, for the given incoming signal, IWAVE.

After Equations (1) and (2) have been implemented, Equations (3) and (4) can then be implemented, for antenna element IANT and incoming signal IWAVE, as:

ARE(IANT) = ARE (IANT) + AMP * COS(PHI)

and

AIM(IANT) = AIM (IANT) + AMP * SIN(PHI).

ARE(IANT) and AIM(IANT), the antenna element voltage variables, were zeroed for all NOA elements before the calculations for the first incoming signal conditions were begun.

For the implementation of the time-dependent phase shift, it will be necessary to store certain intermediate values from the antenna element voltage calculation. These values are stored as:

WPHH(IWAVE) = 0.0, the old reference phase shift for signal IWAVE;

PSTEP(IWAVE) = PST/CONRAD, the reference phase step per scan, for signal IWAVE;

PHIH(IANT,IWAVE) = PHI, the base phase, for element IANT and signal IWAVE;

AMPH(IANT, IWAVE) = AMP, the base amplitude, for element IANT and signal IWAVE, which is also zeroed before calculations for the first incoming signal conditions were begun.

Time Dependent Phase Shift Calculations- Reduced Program Listing Number Four

The time-dependent phase shift calculations are carried out for each sample point for those incoming signals which have a time dependent reference phase shift, i.e. PSTEP(IWAVE) $\neq$ 0. It will also only be necessary to carry out the calculations for those elements which have a non-zero base amplitude for the given signal, i.e. AMPH(IANT,IWAVE) $\neq$ 0.

The first step in the calculations, for a given signal IWAVE, is to determine the reference phase shift, for the present sample point at simulated time T, as: WPPH = PSTEP(IWAVE) * T/SCANT. The reference phases for the past and present sample points, Equations (7) and (8), are then obtained by adding the element base reference phase:

<u>PA1</u> = PHIH (IANT, IWAVE) + WPHH(IWAVE)

and

<u>PA2</u> = PHIH (IANT, IWAVE) + WPHH .

Equations (5) and (6) can then be implemented as:

<u>ARE (IANT)</u> = ARE(IANT) + AMPH(IANT, IWAVE) * (COS(PA2)-COS(PA1))

and

<u>AIM (IANT)</u> = AIM(IANT) + AMPH(IANT, IWAVE) * (SIN(PA2)-SIN(PA1)).

The last step in the calculation, for the given signal, is to store the present reference phase shift in the variable used as the old reference phase shift, i.e. WPHH(IWAVE) = WPPH.

It should be noted that these calculations are bypassed for T = 0, because the phase shift is zero.

<u>Scanning Element and Scanning Bank Voltage Calculations-
Reduced Program Listing Number Five</u>

Once CENT, T, and AMS have been determined for the sample point and the time dependent phase shift calculations have been completed, the scanning bank voltages are calculated in the following manner:

1) Determine the antenna element KC to the left of the first element in the left scanning bank as KC = (CENT-ANOA2)/ANOA + 1.
2) Determine the spacing between a scanning element and the first antenna element to the left as CDEL = (CENT-ANOA2)-(ANOA * (KC-1)) and the first antenna element to the right as CDELP=ANOA-CDEL.

3) Determine the linear displacement factor for antenna elements to the left as CDELAP = CDELP/ANOA and to the right as CDELA = CDEL/ANOA.

4) For the scanning elements in the left bank, IDIR = 1.

5) Zero the bank voltage accumulator SUMI = SUMR = 0.

6) Set ISE = 1 for the first element in the left bank.

7) Find the proper antenna element reference number for the element to the left of ISE as IL = (KC-ISE + 1) and the element to the right as IR = (IL + 1).

8) Determine the noise voltage for the element to the left as ANREL, ANIML, and the element to the right as ANRER, ANIMR.

9) Implement Equations (15) and (16) to find the scanning element voltage.

10) Implement Equations (18) and (19) to find the scanning bank voltage.

11) For the next scanning element in the left bank ISE = (ISE + 1).

12) Return to 7 if ISE ≤ NAS2.

13) Store the left scanning bank voltage as:

    SUMRE(IDIR) = SUMR

    SUMIM(IDIR) = SUMI

14) For the scanning elements in the right bank IDIR = 2.

15) Zero the bank voltage accumulator SUMI = SUMR = 0.

16) Set ISE = 1 for the first element in the right bank.

17) Find the proper antenna element reference number for the element to the left of ISE as IL = (KC + ISE) and the element to the right as IR = (IL + 1).

18) Determine the noise voltage for the element to the left as ANREL, ANIML and the element to the right as ANRER, ANIMR.

19) Implement Equations (15) and (16) to find the scanning element voltage.

20) Implement Equations (18) and (19) to find the scanning bank voltage.

21) For the next scanning element in the right bank ISE = (ISE + 1).

22) Return to 17 if ISE ≤ NAS2.

23) Store the right scanning bank voltage as:

    SUMRE (IDIR) = SUMR

    SUMIM (IDIR) = SUMI

Again it should be noted that it may be necessary to correct IR and IL to fall in the limits 1 to NOA before they are used in any calculations.

Equations (15) and (16) are implemented as:

SRE = (AMS * ARE(IL) + ANREL) * CDELAP + (AMS * ARE(IR) + ANRER) * CDELA

SIM = (AMS * AIM(IL) + ANRML) * CDELAP + (AMS * AIM(IR) + ANIMR) * CDELA

Equations (18) and (19) are implemented as:

SUMI = SUMI + SIM * COSP(ISE) - SRE * SINP(ISE)

SUMR = SUMR + SIM * SINP(ISE) + SRE * COSP(ISE)

where SINP(ISE) and COSP(ISE) are the stored sine and cosine of the phase delay for element ISE.

Determination of the Noise Signal Voltage- Reduced Program Listing Number Six and Seven

The noise voltages are determined by making two successive calls to the computer library pseudo-random number generator (CALL RND(RN, RNDP)) and multiplying the supplied real number RNDP by the relative noise

voltage factor ANOISJ, where RNDP is from a Gaussion distribution and $|RNDP| \leq 5.0$. It is necessary to determine the noise voltages for the antenna elements to the right and left of the scanning elements in different manners for the left and right bank.

For the left bank, since the order in which calculations are made for the scanning elements proceeds from right to left, the noise voltages ANREL, ANIML for element (ISE-1) become the noise voltages ANRER, ANIMR; for element ISE and ANREL, ANIML is determined by consecutive calls to the random number generator. For (ISE= 1), it is necessary to make four calls to the random number generator to determine ANRER, ANIMR and ANREL, ANIML; it will also be necessary to store ANRER, ANIMR as ANRERF, ANIMRF since the antenna element to the right of the first element in the left bank is also the antenna element to the left of the first element in the right bank.

For the right scanning bank, since the order in which calculations are made for the scanning elements proceeds from the left to the right, the noise voltages ANRER, ANIMR for element (ISE-1) become the noise voltages ANREL, ANIML for element ISE and ANRER, ANIMR is determined by consecutive calls to the random number generator. For ISE = 1, the noise voltage ANREL, ANIML is set equal to ANRERF, ANIMRF and the noise voltage ANRER, ANIMR is determined by the random number generator.

Calculation of System Outputs- Reduced Program Listing Number Eight

After the bank voltages have been determined, the output data are determined for the sample point.

The sum data are found as the magnitude of the complex sum of the right and left bank voltages, by implementing Equation (20) as:

SUMR = SUMRE(2) + SUMRE(1)

SUMI = SUMIM(2) + SUMIM(1)

DATAST = SQRT(SUMR ** 2 + SUMI ** 2).

The difference datum is found as the magnitude of the complex difference between the right and left bank voltage, by implementing Equation (21) as:

SUMR = SUMRE(2) - SUMRE(1)

SUMI = SUMIM(2) - SUMIM(1)

DATADT = SQRT(SUMR ** 2 + SUMI ** 2).

The differential phase datum is found as the difference between the phase of the right bank voltage and the phase of the left bank voltage, by implementing Equation (22) as

ANGR = ATAN2 (SUMIM(2), SUMRE(1))

ANGL = ATAN2 (SUMIM(1), SUMRE(2))

DATP = ANGR - ANGL .

where ATAN2 (IM, RE) is defined over the range $-180 <$ ATAN2 (IM, RE) $\leq +180$. It may be necessary to correct DATP to fall between the limits $-180 <$ DATP $\leq +180$.

V. OUTPUT DATA

The simulation program produces both a hard copy and magnetic tape output.

On the first page of the hard copy, for each data run, the input conditions for the simulation are defined along with the data set and data run numbers which are used in locating the data run on the magnetic tape. Succeeding pages contain the output data for each scan in the data run.

After the calculations for each sample point have been completed, as discussed in the last chapter, the output data for sample point IP are stored as:

DATAC (IP) = CENT

DATAS (IP) = DATAST

DATAD (IP) = DATADT

DATAP (IP) = DATP .

As the sample point data are being stored, the sum and difference data are tested to determine their maximum values for the scan; these maximum values are then stored as DATASM and DATADM, respectively. After all of the calculations for the scan have been completed, the output data for the scan are then printed on hard copy.

Along with the numerical values of the output data, a fifty-one-point incremental line printer plot is also displayed on the hard copy. The sum and difference data are normalized by DATASM and DATADM respectively, and then plotted with the maximum values as the right-hand side of the plot. The differential phase data are plotted between the limits -180 degrees on the left and +180 degrees on the right hand side of the

plot. The symbols used in the plot to represent the output data are:

* Sum

+ Difference

X Differential Phase.

Appendix C contains the hard copy output for a sample execution of the program; the necessary input cards for the execution are also shown.

The organization of the output data tape is such that each data set will comprise one tape file. After the file for the last data set on the tape, there is a terminator file which is used in the tape handling procedure. The data set file consists of a series of logical records, one H (or input) record for each data run followed by one S (or output) record for each scan in the data run and a terminator file which consists of one E (or end) record. The structure of the H, S and E records is given in Tables 1, 2, and 3, respectively.

The simulation program, as was noted in the last chapter, has two modes for tape handling operations; the first mode is used for new tapes and the second mode is used for old tapes to which an additional file is to be added. In the first mode it is only necessary to open the tape and position it to its beginning and then the first data set file is written on the tape. The second mode is used to position the tape to the end of the last data set file on the tape; this is done by searching the tape for the terminator file and then writing the new data set file over it. In both modes one and two, after the new data set file has been added to the tape the terminator file is then added to the tape. The only information in the terminator file is the set number of the last data set file which is used in mode two to determine the set number for the next data set file to be added to the tape.

Table 1

The input information for the data run is organized in the H record in the following manner:

AREA(1) =	4H H		
AREA(2) =	SETNUM	- Set number	
AREA(3) =	IRUN	- Run number	
AREA(4) =	NRUN	- Number of runs in the set	
AREA(5) =	NOA	- Number of antenna elements in the array	
AREA(6) =	A	- Radius of the reflecting cylinder	
AREA(7) =	D	- Cylinder to element distance	
AREA(8) =	NAS	- Number of scanning elements	
AREA(9) =	CPHI	- Cophasel angle	
AREA(10) =	FREQC	- Carrier frequency	
AREA(11) =	FREQM	- Modulation frequency	
AREA(12) =	PCAM	- Modulation factor	
AREA(13) =	NWAVE	- Number of incoming signal conditions	
AREA(14) =	ANOIS	- Relative noise level	
AREA(15) =	RN	- Starting Number for pseudo randum number gen.	
AREA(16) =	SECT	- Sector center	
AREA(17) =	ISCAN	- Number of scans in the run	
AREA(18) =	SCANT	- Time to complete on scan	
AREA(19) =	ISAM	- Number of sample points in each scan	
AREA(20) =	SAMI	- Spacing between sample points	
AREA(21) =	WAMP	- Relative signal amplitude	
AREA(22) =	WPHI	- Reference phase	For
AREA(23) =	AZM	- Azimuthal angle of arrival	IWAVE = 1
AREA(24) =	ELEV	- Elevation angle of arrival	
AREA(25) =	PST	- Time Dept. phase shift	
AREA(26) =	WAMP	-	
AREA(27) =	WPHI	-	For
AREA(28) =	AZM	-	IWAVE = 2
AREA(29) =	ELEV	-	
AREA(30) =	PST	-	
AREA(31) =			
AREA( ) =			
AREA( ) =			
AREA( ) =			

To access the information for signal conditions IWAVE:

```
WAMP = AREA(21 + (IWAVE-1) * 5)
WPHI = AREA(22 + (IWAVE-1) * 5)
AZM  = AREA(23 + (IWAVE-1) * 5)
ELEV = AREA(24 + (IWAVE-1) * 5)
PSR  = AREA(25 + (IWAVE-1) * 5)
```

Table II

The output information for a scan is organized in the S record in the following manner:

```
AREA( 1) = 4H     S
AREA( 2) = SETNUM - Set number
AREA( 3) = IRUN   - Run number
AREA( 4) = NRUN   - Number of runs in the scan
AREA( 5) = IS     - Scan number
AREA( 6) = DATASM - Maximum value of the sum data
AREA( 7) = DATADM - Maximum value of the difference data
AREA( 8) =        -
AREA( 9) =        -      Blank
AREA(10) =        -
AREA(11) = CENT   - Boresight setting
AREA(12) = DATAST - Sum data                          For
AREA(13) = DATADT - Difference data                   IP=1
AREA(14) = DATP   - Differential phase data
AREA(15) = CENT   - Boresight setting
AREA(16) = DATAST - Sum data                          For
AREA(17) = DATADT - Difference data                   IP=2
AREA(18) = DATP   - Differential phase data
AREA(19) = CENT   -
AREA(20) = DATAST -                                   For
AREA(21) = DATADT -                                   IP=3
AREA(22) = DATP   -
AREA(23) =        -
AREA(24) =
AREA(  ) =
AREA(  )
AREA
```

To access the output data for sample point IP:

```
CENT   = AREA(11 + (IP-1) * 4)
DATAST = AREA(12 + (IP-1) * 4)
DATADT = AREA(13 + (IP-1) * 4)
DATAP  = AREA(14 + (IP-1) * 4)
```

Table III

The E record is organized in the following manner:

```
AREA( 1) = 4H     E
AREA( 2) = SETNUM - Set number of last data set file
```

The method that should be used to locate a given data run, defined by SETNUM, IRUN, is to test the first record in each file until AREA(2) = SETNUM and then check each record in the file until AREA(1) = 4H _ _ _H and AREA(3) = IRUN. Appendix D contains a segment of a program which can be used to properly locate a given data run.

Appendix E contains the listing of program STRO, standing for Simulation Tape Read Out, which is used to obtain a hard copy print out of all the information on the output tape.

REFERENCES

1. W. C. McClurg, HSDS-A High Speed Data System, (RRL Publication No. 339, University of Illinois Reports.) Technical Report No. 4, Contract N00014-67-A-0305-0002, March 1968.

2. E. Jones, Jr., A Digital Simulation of the Wullenweber Direction Finding System, (RRL Publication No. 296, University of Illinois Reports.) Technical Report No. 16, Contract NOBSR 89229, December 1965.

3. P. S. Carter, "Antenna Arrays Around Cylinders", Proceedings Institute of Radio Engineers, Vol. 31, No. 12, pp. 671-693, December 1943.

APPENDIX A

LISTING OF PROGRAM GCAAS

```
H       NAME GCAAS;
H       EQUIP=CARDRE,PRINTE;
H       SINGLE (AREA,DEAN);
C
C
C       PROGRAM:        GCAAS
C       STANDING FOR:   GENERAL CIRCULAR ANTENNA ARRAY SIMULATOR
C
C       WRITTEN BY:     ROY F HUNNINGHAUS
C
C       WRITTEN FOR:    RADIOLOCATION RESEARCH LABORATORY
C                       DEPARTMENT OF ELECTRICAL ENGINEERING
C                       UNIVERSITY OF ILLINOIS
C
C       COMPLETED:      MAY, 1970
C       REVISED:        OCTOBER, 1970 - FOR NEW TAPE HANDLING PROCEDURES
C
C       ******************************************************************
C
C       INPUT CARDS NECESSARY FOR OPERATION:
C
C       ONE PROGRAM OPERATION CARD:
C       (I5)      NRUN    * NUMBER OF DATA RUNS IN DATA SET
C       (I5)      ITAPE   * TAPE DRIVE NUMBER
C       (I5)      MODE    * TAPE OPERATION MODE
C                           ENTER 1 IF DATA STARTS A NEW TAPE
C                           ENTER 2 IF DATA IS ADDED TO AN OLD TAPE
C
C       THE FOLLOWING CARDS ARE NEEDED FOR EACH DATA RUN OF THE DATA SET
C       ANTENNA INFORMATION CARD:
C       (I5)      NOA     * NUMBER OF ANTENNA ELEMENTS IN ARRAY
C       (F10.2)   A       * DISTANCE FROM CENTER OF ARRAY TO THE REFLECTING
C                           SCREEN IN METERS
C       (F10.2)   B       * DISTANCE FROM REFLECTING SCREEN TO THE ANTENNA
C                           ELEMENT IN METERS
C       (I5)      NAS     * NUMBER OF SCANNING ELEMENTS
C       (F10.2)   PHI     * COPHASEL ANGLE
C
C       GENERAL SIGNAL INFORMATION CARD:
C       (I5)      NWAVE   * NUMBER OF INCOMING SIGNALS
C       (F10.4)   FRECC   * CARRIER FREQUENCY IN MEG. HZ.
C       (F10.4)   FREQM   * MODULATING FREQUENCY IN KIL. HZ.
C       (F10.4)   FCAM    * AMPLITUDE MODULATION FACTOR (1.0 TO 0.0)
C
C       INCOMING SIGNAL CONDITION CARD,
C       ONE CARD FOR EACH SET OF SIGNAL CONDITIONS
C       I. E. SAME NUMBER OF CARDS AS NUMBER ENTERED FOR NWAVE:
C       (F8.2)    WAMP    * SIGNAL AMPLITUDE (0.0 TO 1.0)
C       (F8.2)    WPHI    * SIGNAL PHASE IN DEGREES
C       (F8.2)    AZM     * AZIMUTHAL ANGLE OF ARRIVAL IN DEGREES
C       (F8.2)    ELEV    * ELEVATION ANGLE OF ARRIVAL IN DEGREES
C       (F8.2)    PST     * SIGNAL PHASE STEP IN DEGREES PER SCAN
C
C       NOISE INFORMATION CARD:
C       (F10.4)   FNOIS   * RMS VALUE OF NOISE SIGNAL (0.0 TO 1.0)
C       (I5)      IX      * STARTING NUMBER FOR PSEUDO RANDOM NO. GENERATOR
C                           ENTER 0
C
C       SCANNING OPERATION INFORMATION CARD:
C       (F10.2)   SECT    * SECTOR CENTER IN DEGREES
C       (F10.2)   SCANT   * TIME FOR ONE SCAN IN SECONDS
```

```
C       (I5)      ISCAN   * NUMBER OF SCANS IN THE DATA RUN
C       (I5)      ISAM    * NUMBER OF SAMPLE POINTS IN EACH SCAN
C       (F10.2) SAMI    * ANGLE BETWEEN SAMPLE POINTS IN DEGREES
C
C       ****************************************************************
C       PROGRAM LIMITS
C
C       INPUT:
C       MAXIMUM NUMBER OF SIGNAL CONDITIONS          5
C       AZMUTHAL ANGLES SHOULD BE EXPRESSED BETWEEN THE LIMITS OF
C       0.0 DEGREES AND 359.99- DEGREES
C
C       OUTPUT:
C       MAXIMUM NUMBER OF SAMPLE POINTS / SCAN   100
C
C       OPERATION:
C       MAXIMUM NUMBER OF ANTENNA ELEMENTS        360
C       MAXIMUM NUMBER OF SCANNING ANTENNA        100 (MUST BE AN EVEN NO.)
C
C       ****************************************************************
C       TAPE HANDLING
C
C       THE OUTPUT DATA WILL BE STORED ON THE TAPE MOUNTED ON DRIVE ITAPE
C
C       THE OLD DATA TAPE, IF ANY, SHOULD BE MOUNTED ON DRIVE ITAPE
C       THE TAPE WILL BE ADVANCED TO THE END OF THE OLD DATA AND THE NEW
C       DATA WILL BE STORED BEGINNING AT THAT POINT ON THE TAPE
C
C       ****************************************************************
C
C       DIMENSION ARRAYS
C
        DIMENSION COSP(50),SINP(50)
        DIMENSION ARE(360),AIM(360)
        DIMENSION SUMRE(2),SUMIM(2)
        DIMENS ON DATAS(100),DATAD(100),DATAP(100),DATAC(100)
        DIMENSION WPHH(5),PSTEP(5)
        DIMENSION PHIH(360,5),AMPH(360,5)
        DIMENS ON ALINE(51),AMARK(11)
        DIMENSION AREA(410),DEAN(650)
C
        HH=4H    H
        SH=4H    S
        EH=4H    E
C
C       INITIALIZE LINE PRINTER
C
        DO 900 IP=1,51
  900   ALINE(IP)=0
        DO 901 IP=1,11
  901   AMARK(IP)=27
C
C       DEFINE NATURAL CONSTANTS
C
        VEC=299.8
        PI=3.14159265
        TWOP = PI*2
        CONRAD=360/TWOP
C
C       READ PROGRAM OPERATION INFORMATION
C
```

```
      IRUN=0
      READ 9008,NRUN,ITAPE,MODE
C
C     OPEN TAPE ON DRIVE ITAPE
C
      DFAS=600
      CALL SETHN(ITAPE,1)
      CALL FXBLK(ITAPE,1)
      CALL BLKLN(ITAPE,0,0)
C
      GO TO (924,914),MODE
C
C     TAPE MODE NO. 2
C     ADVANCE TAPE TO END OF OLD DATA
C
  914 CONTINUE
  915 ASSIGN 8800 TO LAST
  916 CALL OPEN(DFAN,DFAS,ITAPE,0,4HSIMU)
      CALL RDLR(DFAN,AREA,LAST)
      CALL CLOSE(DFAN)
      IF (AREA(1)-EH) 917,918,917
  917 CALL SETFD(DFAN)
      GO TO 916
  918 CALL SETBK(DFAN)
      CALL OPEN(DFAN,DFAS,ITAPE,0,4HSIMU)
      SETNUM=AREA(2)
      GO TO 930
C
C     TAPE MODE NO. 1
C
  924 CONTINUE
  925 CALL OPEN(DFAN,DFAS,ITAPE,0,4HSIMU)
      SETNUM=0
C
  930 SETNUM=SETNUM+1000
C
C     BEGINNING OF DATA RUN
C
  950 IRUN=IRUN+1
C
C
C     READ ANTENNA INFORMATION AND GENERAL SIGNAL INFORMATION
C
      READ 9009,NOA,A,D,NAS,CPHI
      READ 9010,NWAVE,FREQC,FREQM,FCAM
C
C     DETERMINE DATA RUN OPERATION CONSTANTS
C
      NOA4=NOA/4
      ANOA=360/NOA
      ANOA2=ANOA/2
      NAS2=NAS/2
      WL=VEC/FREQC
      CONST1=TWOPI*D/WL
      CONST2=TWOPI*A/WL
      CONW=TWOPI*FREQM*1000
C
C     CALCULATE PHASE DELAYS FOR SCANNING ANTENNA ELEMENTS
C
      CONCHI=COS(CPHI/CONRAD)*CONS12
      COSM=COS(((NAS2-1)*ANOA+ANOA2)/CONRAD)
```

```
      DO 999 ISE=1,NAS2
      PDELAY=CONCHI*(COS(((ISE-1)*ANOA+ANOA2)/CONRAD))-COSM)
      COSP(ISE)=COS(PDELAY)
      SINP(ISE)=SIN(PDELAY)
  999 CONTINUE
C
C     PRINT H RECORD INFORMATION
C
      PRINT 9019,SETNUM,IRUN,NRUN
      PRINT 9020,NOA,A,D,NAS,CPHI,FREQC,FREQM,PCAM,NWAVE
      PRINT 9021
C
C     STORE H RECORD INFORMATION
C
      AREA( 1)=HH
      AREA( 2)=SETNUM
      AREA( 3)=IRUN
      AREA( 4)=NRUN
      AREA( 5)=NOA
      AREA( 6)=A
      AREA( 7)=D
      AREA( 8)=NAS
      AREA( 9)=CPHI
      AREA(10)=FREQC
      AREA(11)=FREQM
      AREA(12)=PCAM
      AREA(13)=NWAVE
      KKK=21
C
C     ZERO ANTENNA ELEMENT ARRAYS
C
      DO 1000 IANT=1,NOA
      ARE(IANT)=0.0
      AIM(IANT)=0.0
      DO 1000 IWAVE=1,NWAVE
      AMPH(IANT,IWAVE)=0.0
 1000 CONTINUE
C
      IWAVE=1
C
C     READ AND PRINT SIGNAL CONDITION
C
 1001 READ 9011,WAMP,WPHI,AZM,ELEV,PST
      PRINT 9022,IWAVE,WAMP,WPHI,AZM,ELEV,PST
C
      WPH=WPHI/CONRAD
      COSELV=COS(ELEV/CONRAD)
      COSAMP=COSELV*WAMP
      CONE1=CONST1*COSELV
      CONE2=CONST2*COSELV
      WPHH(IWAVE)=0.0
      PSTEP(IWAVE)=PST/CONRAD
C
C     STORE W RECORD INFORMATION
C
      AREA(KKK  )=WAMP
      AREA(KKK+1)=WPHI
      AREA(KKK+2)=AZM
      AREA(KKK+3)=ELEV
      AREA(KKK+4)=PST
      KKK=KKK+5
```

```
C
C      DETERMINE ANTENNA ELEMENT TO THE LEFT OF THE SIGNAL AZIMUTH
C      AND THE ANGLES BETWEEN THE AZMIMUTH AND ADJACENT ANTENNA ELEMENTS
C
       K=(AZM/ANOA)+1
       DELK=AZM-ANOA*(K-1)
       DELKP=ANOA-DELK
C
C      GO TO LEFT FOR IDIR=1 AND RIGHT FOR IDIR=2
C
       DO 1014 IDIR=1,2
C
C      PREFORM OPERATION FOR ANTENNA ELEMENTS UP TO 90 DEG. FROM AZIMUTH
C
 1002  DO 1013 IAW=1,NOA4
       GO TO (1003,1008),IDIR
C
C      FIND ANTENNA NUMBER FOR OPERATION TO LEFT
C
 1003  IANT=K+1-IAW
       IF (IANT) 1004,1004,1005
 1004  IANT=NOA+IANT
 1005  THE=ANOA*(1-IAW)-DELK
       IF (ABSF(THE)-90) 1007,1007,1006
 1006  THE=-90
 1007  GO TO 1012
C
C      FIND ANTENNA NUMBER FOR OPERATION TO RIGHT
C
 1008  IANT=K+IAW
       IF (NOA-IANT) 1009,1010,1010
 1009  IANT=IANT-NOA
 1010  THE=DELKP+ANOA*(IAW-1)
       IF (ABSF(THE)-90) 1012,1012,1011
 1011  THE=90
C
C      CALCULATE THE COMPLEX ANTENNA VOLTAGE OF THE GIVEN ANTENNA
C
 1012  COSTHE=COS(THE/CONRAD)
       AMP=CONAMP*SIN(CONE1*COSTHE)
       PHI=CONE2*COSTHE+WPH
       ARE(IANT)=ARE(IANT)+AMP*COS(PHI)
       AIM(IANT)=AIM(IANT)+AMP*SIN(PHI)
C
C      STORE BASE PHASE STEP INFORMATION
C
       PHIH(IANT,IWAVE)=PHI
       AMPH(IANT,IWAVE)=AMP
 1013  CONTINUE
 1014  CONTINUE
       IWAVE=IWAVE+1
       IF (NWAVE-IWAVE) 1016,1001,1001
 1016  CONTINUE
C
C      READ NOISE AND SCANNING OPERATION INFORMATION
C
       READ 9013,ANOIS,BN
       READ 9012,SECT,SCANT,ISCAN,ISAM,SAMI
C
C      CALCULATE SCANNING OPERATION CONSTANTS
C
```

```
      WIDTH=(ISAM-1)*SAMI
      SIDE=SECT-WIDTH/2
      IF (SIDE) 1150,1151,1151
 1150 SIDE=360+SIDE
 1151 CONTINUE
      DELT=SCANT*SAMI/360
      ANOISJ=.707*ANOIS
C
C     PRINT H RECORD INFORMATION
C
      PRINT 9023,ANOIS,RN,SECT,ISCAN,SCANT,ISAM,SAMI
C
C     STORE H RECORD INFORMATION
C
      AREA(14)=ANOIS
      AREA(15)=RN
      AREA(16)=SECT
      AREA(17)=ISCAN
      AREA(18)=SCANT
      AREA(19)=ISAM
      AREA(20)=SAMI
C
C     WRITE H RECORD INFORMATION ON TO TAPE
C
      CALL WRLR(DFAN,AREA,50)
C
C     BEGINNING OF SCAN
C
      DO 1250 IS=1,ISCAN
C
C     STORE S RECORD INFORMATION
C
      AREA( 1)=SH
      AREA( 2)=SETNUM
      AREA( 3)=IRUN
      AREA( 4)=NRUN
      AREA( 5)=IS
C
C     ZERO MAX OUTPUT DATA VARIABLES
C
      DATASM=0.0
      DATAPM=0.0
C
C     INITIALIZE TIME
C
      T=(IS-1)*SCANT-DELT
C
C     BEGINNING OF CALCULATIONS FOR SAMPLE POINT
C
      DO 1228 IP=1,ISAM
C
C     CALCULATE SAMPLE CENTER
C
      CENT=(IP-1)*SAMI+SIDE
      IF (CENT-360) 1153,1152,1152
 1152 CENT=CENT-360
 1153 CONTINUE
C
C     ADVANCE TIME
C
      T=T+DELT
```

```
C
C      SKIP WAVE PHASE STEP CALCULATIONS FOR FIRST SCAN, FIRST SAMPLE
C
       IF (T) 1190,1190,1160
C
C      BEGINNING OF WAVE PHASE STEP CALCULATIONS
C
 1160 DO 1172 IWAVE=1,NWAVE
C
C      IF WAVE PHASE STEP =0.0 SKIP CALCULATIONS
C
       IF (PSTEP(IWAVE)) 1161,1172,1161
C
C      CALUCLATE PRESENT WAVE PHASE
C
 1161 WPPH=PSTEP(IWAVE)*T/SCANT
C
C      CALCULATE NEW ANTENNA VOLTAGE FOR ALL ELEMENTS IN ARRAY
C
       DO 1170 IANT=1,NOA
       IF (AMPH(IANT,IWAVE)) 1169,1170,1169
 1169 PA1=PHWH(IANT,IWAVE)+WPHH(IWAVE)
       PA2=PHWH(IANT,IWAVE)+WPPH
       ARE(IANT)=ARE(IANT)+AMPH(IANT,IWAVE)*(COS(PA2)-COS(PA1))
       AIM(IANT)=AIM(IANT)+AMPH(IANT,IWAVE)*(SIN(PA2)-SIN(PA1))
 1170 CONTINUE
C
C      STORE PRESENT WAVE PHASE
C
 1171 WPHH(IWAVE)=WPPH
 1172 CONTINUE
 1190 CONTINUE
C
C      CALCULATE MODULATING FACTOR FOR TIME T
C
       AMS=(1-PCAM)+PCAM*COS(CONW*T)
C
C      DETERMINE ANTENNA ELEMENT TO THE LEFT OF THE SAMPLE CENTER AND THE
C      ANGLES BETWEEN THE SAMPLE CENTER AND ADJACENT ANTENNA ELEMENTS
C
       KC=(CENT-ANOA2)/ANOA+1
       CDEL=(CENT-ANOA2)-ANOA*(KC-1)
       CDELP=ANOA-CDEL
C
C      CALCULATE THE LINEAR INTERPOLATION FACTORS
C
       CDELA=CDEL/ANOA
       CDELAP=CDELP/ANOA
C
C      IF KC IS NOT BETWEEN THE LIMITS 1 - NOA, CORRECT THE VALUE OF KC
C
       IF (KC) 1194,1194,1195
 1194 KC=NOA+KC
 1195 IF (KC-NOA) 1197,1197,1196
 1196 KC=KC-NOA
C
C      LEFT BANK FOR IDIR=1 AND RIGHT BANK FOR IDIR=2
C
 1197 DO 1220 IDIR=1,2
C
C      ZERO BANK ACCOMULATOR
```

```
C
      SJMI=0
      SJMR=0
C
C     PREFORM OPERATION FOR EACH ELEMENT IN THE BANK
C
 1199 DO 1217 ISE=1,NAS2
      GO TO (1200,1204),IDIR
C
C     FIND ELEMENTS TO THE LEFT AND RIGHT OF SCANNING ELEMENT ISE
C     FOR THE LEFT SCANNING BANK
C
 1200 IL=KC-(ISE-1)
      IR=IL+1
C
C     CALCULATE THE NOISE VOLTAGE FOR THE ANTENNA ELEMENT COMMON TO
C     BOTH THE LEFT AND RIGHT SCANNING ANTENNA BANKS
C
      IF (ISE-1) 1201,1201,1202
 1201 CALL RND(RN,RNDP)
      ANRERF=ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIMRF=ANOISJ*RNDP
      ANRER=ANRERF
      ANIMR=ANIMRF
      GO TO 1203
C
C     CALCULATE THE NOISE VOLTAGE FOR THE ANTENNA ELEMENTS TO THE
C     LEFT AND RIGHT OF THE SCANNING ELEMENT
C
 1202 ANRER=ANREL
      ANIMR=ANIML
 1203 CALL RND(RN,RNDP)
      ANREL=ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIML=ANOISJ*RNDP
      GO TO 1208
C
C
C     FIND ELEMENTS TO THE LEFT AND RIGHT OF SCANNING ELEMENT ISE
C     FOR THE RIGHT SCANNING BANK
C
 1204 IL=KC+ISE
      IR=IL+1
C
C     CALCULATE THE NOISE VOLTAGE FOR THE ANTENNA ELEMENTS TO THE
C     LEFT AND RIGHT OF THE SCANNING ELEMENT
C
      IF (ISE-1) 1205,1205,1206
 1205 ANREL=ANRERF
      ANIML=ANIMRF
      GO TO 1207
 1206 ANREL=ANRER
      ANIML=ANIMR
 1207 CALL RND(RN,RNDP)
      ANRER=ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIMR=ANOISJ*RNDP
C
C     CORRECT IR AND IL TO FIT BETWEEN THE LIMITS 1 - NOA
C
```

```
 1208 IF (IL) 1209,1209,1210
 1209 IL=NOA+IL
 1210 IF (IL-NOA) 1212,1212,1211
 1211 IL=IL-NOA
 1212 IF (IR) 1213,1213,1214
 1213 IR=NOA+IR
 1214 IF (IR-NOA) 1216,1216,1215
 1215 IR=IR-NOA
 1216 CONTINUE
C
C      FIND THE VOLTAGE OF THE SCANNING ELEMENT
C
       SRE=(AMS*ARE(IL)+ANREL)*CDELAP+(AMS*ARE(IR)+ANRER)*CDELA
       SIM=(AMS*AIM(IL)+ANIML)*CDELAP+(AMS*AIM(IR)+ANIMR)*CDELA
C
C      ADD ON THE PHASE DELAY AND ADD THE VOLTAGE TO THE BANK ACCUMULATOR
C
       SUMI=SUMI+SIM*COSP(ISE)-SRE*SINP(ISE)
       SUMR=SUMR+SIM*SINP(ISE)+SRE*COSP(ISE)
 1217 CONTINUE
C
C      STORE THE BANK VOLTAGE
C
       SUMRE(IDIR)=SUMR
       SUMIM(IDIR)=SUMI
 1220 CONTINUE
C
C      CALCULATE THE VOLTAGE SUMM OF THE RIGHT AND LEFT BANK
C
       SUMR=SUMRE(1)+SUMRE(2)
       SUMI=SUMIM(1)+SUMIM(2)
       DATAST=SQRT(SUMR**2+SUMI**2)
C
C      CALCULATE THE VOLTAGE DIFFERENCE BETWEEN THE RIGHT AND LEFT BANK
C
       SUMR=SUMRE(2)-SUMRE(1)
       SUMI=SUMIM(2)-SUMIM(1)
       DATADT=SQRT(SUMR**2+SUMI**2)
C
C      CALCULATE THE PHASE DIFFERENCE BETWEEN THE RIGHT AND LEFT BANK
C      AND ADJUST TO FIT BETWEEN THE LIMITS -179.999 TO 180 DEGREES
C
       ANGR=ATAN2(SUMIM(2),SUMRE(2))*CONRAD
       ANGL=ATAN2(SUMIM(1),SUMRE(1))*CONRAD
       DATP=ANGR-ANGL
       IF (DATP+180) 1221,1221,1222
 1221 DATP=DATP+360
       GO TO 1224
 1222 IF (DATP-180) 1224,1224,1223
 1223 DATP=DATP-360
 1224 CONTINUE
C
C      STORE THE SCAN OUTPUT DATA
C
       DATAS(IP)=DATAST
       DATAD(IP)=DATADT
       DATAP(IP)=DATP
       DATAC(IP)=CENT
C
C      STORE S RECORD INFORMATION
C
```

```
      III=(I^-1)*4+11
      AREA(III   )=CENT
      AREA(III+1)=DATAST
      AREA(III+2)=DATADT
      AREA(III+3)=DATP
C
C     FIND THE MAXIMUM SUM AND DIFFERENCE VALUE
C
      IF (ABSF(DATAST)-DATASM) 1226,1226,1225
 1225 DATASM=DATAST
 1226 IF (ABSF(DATADT)-DATADM) 1228,1228,1227
 1227 DATADM=DATADT
 1228 CONTINUE
C
C     STORE S RECORD INFORMATION
C
      AREA( 6)=DATASM
      AREA( 7)=DATADM
C
C     WRITE S RECORD INFORMATION ON TO TAPE
C
      CALL WRER(DFAN,AREA,410)
C
C     PRINT S RECORD INFORMATION
C
      PRINT 9019,SETNUM,IRUN,NRUN
      PRINT 9025,IS,DATASM,DATADM
      PRINT 9026
C
C     PRINT S RECORD SAMPLE POINT OUTPUT DATA
C     PRINT S FILE SAMPLE POINT OUTPUT DATA
C
      DO 1240 IP=1,ISAM
      PRINT 9027,DATAC(IP),DATAS(IP),DATAD(IP),DATAP(IP),
     1(AMARK(II),II=1,11)
C
C     PREFORM OPERATIONS FOR THE LINE PRINTER PLOT
C
      I1=((DATASM/100+DATAS(IP))/DATASM)*50+1
      I2=((DATADM/100+DATAD(IP))/DATADM)*50+1
      I3=((DATAP(IP)+183.6)/360)*50+1
      ALINE(I1)=46
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I1)=0
      ALINE(I2)=44
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I2)=0
      ALINE(I3)=24
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I3)=0
 1240 CONTINUE
 1250 CONTINUE
C
C     END OF DATA RUN, START CALCULATIONS OVER FOR NEXT DATA RUN,
C     OR CLOSE TAPE AND EXIT PROGRAM IF LAST DATA RUN HAS BEEN COMPLETED
C
      IF (NRUN-IRUN) 8995,8995,950
C
C     THE OLD DATA RUNS OFF THE END OF THE TAPE, PRINT ERROR STATEMENT
C     AND TERMINATE EXECUTION OF PROGRAM
C
```

```
 8800 PRINT 9050
      GO TO 8999
C
C     WRITE THE TERMINAL FILE ONTO THE END OF THE TAPE
C
 8995 CALL CLOSE(DFAN)
 8996 CALL OPEN(DFAN,DFAS,ITAPE,0,4HSIMU)
      AREA( 1)=FH
      CALL WRIR(DFAN,AREA,2)
C
C     CLOSE AND REWIND THE TAPE AND EXIT THE PROGRAM
C
 8999 CALL CLOSE(DFAN)
      CALL SETHN(ITAPE,1)
      CALL EXIT
C
C     ***************************************************************
C
C     THE I/O FORMATS ARE AS FOLLOWS
C
 9008 FORMAT (3I5)
 9009 FORMAT (I5,2F10.2, I5, F10.2)
 9010 FORMAT ( I5,3F10.4)
 9011 FORMAT (5F8.2)
 9012 FORMAT (2F10.2,2I5,F10.2)
 9013 FORMAT (F10.4,I5)
 9019 FORMAT (1H1/5X,13HSET NUMBER = ,I10,14H * RUN NUMBER ,I3,4H OF ,
     1I3,5H RUNS)
 9020 FORMAT (                                        /5X,25HANTENNA ARRA
     1Y INFORMATION// 5X,20HNUMBER OF ANTENNAS =,17X,F6.2/5X,32HDISTANC
     2E FROM CENTER TO SCREEN =,5X,F6.2,7H METERS/  5X,33HDISTANCE FROM
     3SCREEN TO ANTENNA =,4X,F6.2,7H METERS//  5X,12HSCANNER MODE//
     45X,29HNUMBER OF SCANNING ANTENNAS =,8X,F6.2/ 5X,16HCOPHASAL ANGLE
     5=,21X,F6.2,8H DEGREES// 5X,16HWAVE INFORMATION// 5X,19HCARRIER FRE
     6QUENCY =,18X,F6.2,4H MHZ/ 5X,22HMODULATION FREQUENCY =,15X,F6.2,4H
     7 KHZ/5X,23HPERCENT OF MODULATION =,14X,F6.2/   5X,31HNUMBER OF INC
     8IDENT WAVEFRONTS =,6X,F6.2/)
 9021 FORMAT (5X,4HWAVE,5X,4HWAVE,4(6X,4HWAVE),6X,5HPHASE/5X,4HNUMB,5X,
     13HAMP,7X,5HPHASE,5X,3HAZM,7X,4HELEV,6X,4HSTEP/)
 9022 FORMAT (5X,I3,1X,5(4X,F6.2))
 9023 FORMAT (/5X,17HNOISE INFORMATION// 5X,19HSTANDARD DEVATION =,18X,F
     16.2              / 5X,13HRND STARTER =,24X,F6.2// 5X,27HANTENNA ARRAY
     2 SCAN SETTINGS//5X,15HSECTOR CENTER =,22X,F6.2,8H DEGREES/
     3 5X,18HNUMBER OF SCANS = ,19X,F6.2/                      5X ,15HS
     4CAN TIME =      ,22X,F6.2,8H SEC      / 5X,25HNUMBER OF SAMPLE POINTS
     5=,12X,F6.2/ 5X,26HINCREMENT BETWEEN POINTS =,11X,F6.2,8H DEGREES)
 9025 FORMAT (     5X,13HSCAN NUMBER =,I3// 5X,14HMAX SUM DATA =,2X,F8.2/
     15X,14HMAX DIF DATA =,2X,F8.2/)
 9026 FORMAT (/7X,4HBORE,7X,3HSUM,8X,3HDIF,8X,5HPHASE/ 7X,5HSIGHT,6X,4HD
     1ATA,2(7X,4HDATA)/)
 9027 FORMAT (2X,4(3X,F8.2),5X,A1.4,10(4X,A1.4))
 9030 FORMAT (1H+,50X,51A1.4)
 9050 FORMAT (1H1/ 5X, 37HTHE DATA RUNS OFF THE END OF THE TAPE/
     1  5X,  28HPROGRAM WILL NOT BE EXECUTED)
C
C     ***************************************************************
C
      END
```

APPENDIX B

REDUCED PROGRAM LISTINGS

```
REDUCED PROGRAM LISTING NUMBER ONE
     THE BASIC OPERATION OF THE PROGRAM


*****************************************************************
*      *  START                                                 *
*                                                               *
*****************************************************************

       VEC    =299.8
       PI     =3.14159265
       TWOPI  =PI*2
       CONRAD=360/TWOPI

*****************************************************************
*                                                               *
*                                                               *
*****************************************************************

       IRUN   =0
       READ 9008,NRUN,ITAPR,MODE

*****************************************************************
*                                                               *
*                                                               *
*****************************************************************

       GO TO (924,914),MODE
914    CONTINUE

*****************************************************************
*      *  TAPE MODE 2 - OLD TAPE                                *
*      *  ADVANCE TAPE TO END OF OLD DATA                       *
*      *  SETNUM=SETNUM OF LAST DATA SET                        *
*****************************************************************

       GO TO 930
924    CONTINUE

*****************************************************************
*      *  TAPE MODE 1 - NEW TAPE                                *
*      *  INITIALIZE TAPE                                       *
*****************************************************************

       SETNUM=0
930    SETNUM=SETNUM+1000
950    IRUN   =IRUN+1

*****************************************************************
*                                                               *
*                                                               *
*****************************************************************
```

```
        READ 9009,NOA,A,D,NAS,CPHI
        READ 9010,NWAVE,FREQC,FREQM,PCAM
        NOA4   =NOA/4
        ANOA   =360/NOA
        ANOA2  =ANOA/2
        NAS2   =NAS/2
        WL     =VEC/FREQC
        CONST1=TWOPI*D/WL
        CONST2=TWOPI*A/WL
        CONW   =TWOPI*FREQM*1000

*************************************************************
*      * PHASE DELAY CALCULATIONS                           *
*                                                           *
*************************************************************

*************************************************************
*                                                           *
*                                                           *
*************************************************************

        DO 1000 IANT=1,NOA
        AIM(IANT)=0.0
        ARE(IANT)=0.0
        DO 1000 IWAVE=1,NWAVE
        AMPH(IANT,IWAVE)=0.0
1000    CONTINUE
        IWAVE =1
1001    CONTINUE
        READ 9011,WAMP,WPHI,AZM,ELEV,PST
        WPH    =WPHI/CONRAD
        COSELV=COS(ELEV/CONRAD)
        COSAMP=COSELV*WAMP
        CONE1  =CONST1*COSELV
        CONE2  =CONST2*COSELV

*************************************************************
*                                                           *
*                                                           *
*************************************************************

*************************************************************
*      * ANTENNA ELEMENT VOLTAGE CALCULATIONS               *
*                                                           *
*************************************************************

        IWAVE =IWAVE+1
        IF (NWAVE-IWAVE) 1016,1001,1001
1016    CONTINUE
        READ 9013,ANOIS,RN
        ANOISJ=.707*ANOIS
        READ 9012,SECT,SCANT,ISCAN,ISAM,SAM2
        WIDTH =(ISAM-1)*SAMI
        SIDE   =SECT-WIDTH/2
        IF (SIDE) 1150,1151,1151
1151    SIDE   =360+SIDE
1151    CONTINUE
        DELT   =SCANT*SAMI/360
```

```
*******************************************************************
*                                                                 *
*                                                                 *
*******************************************************************

      DO 1250 IS=1,ISCAN

*******************************************************************
*                                                                 *
*                                                                 *
*******************************************************************

      T      =(IS-1)*SCANT-DELT
      DO 1228 IP=1,ISAM
      CENT   =(IP-1)*SAMI+SIDE
      IF (CENT-360) 1153,1152,1152
1152  CENT   =CENT-360
1153  CONTINUE
      T      =T+DELT
      AMS    =(1-PCAM)+PCAM*COS(CONW*T)

*******************************************************************
*     * PHASE STEP CALCULATIONS                                   *
*                                                                 *
*******************************************************************

*******************************************************************
*     * SCANNING BANK VOLTAGE CALCULATIONS                        *
*                                                                 *
*******************************************************************

*******************************************************************
*     * OUTPUT DATA CALCULATIONS                                  *
*                                                                 *
*******************************************************************

*******************************************************************
*                                                                 *
*                                                                 *
*******************************************************************

1228  CONTINUE

*******************************************************************
*                                                                 *
*                                                                 *
*******************************************************************

1250  CONTINUE
      IF (NRUN-IRUN) 8995,8995,950
8995  CONTINUE

*******************************************************************
*                                                                 *
*                                                                 *
*     * END                                                       *
*******************************************************************
```

REDUCED PROGRAM LISTING NUMBER TWO
PHASE DELAY CALCULATIONS

```
      CONCHI=COS(CPHI/CONRAD)*CONST2
      COSM  =COS(((NAS2-1)*ANOA+ANOA2)/CONRAD)
      DO 999 ISE=1,NAS2
      PDELAY=CONCHI*(COS(((ISE-1)*ANOA+ANOA2)/CONRAD)-COSM)
      COSP(ISE)=COS(PDELAY)
      SINP(ISE)=SIN(DELAY)
999   CONTINUE
```

REDUCED PROGRAM LISTING NUMBER THREE
ANTENNA ELEMENT VOLTAGE CALCULATIONS

```
      K      =(AZM/ANOA)+1
      DELK   =AZM-ANOA*(K-1)
      DELKP  =ANOA-DELK
      WPHH(IWAVE)=0.0
      PSTEP(IWAVE)=PST/CONRAD
      DO 1014 IDIR=1,2
1002  DO 1013 IAW=1,NOA4
      GO TO (1003,1008),IDIR
1003  IANT   =K+1-IAW
      IF (IANT) 1004,1004,1005
1004  IANT   =NOA+IANT
1005  THE    =ANOA*(1-IAW)-DELK
      IF (ABSF(THE)-90) 1007,1007,1006
1006  THE    =-90
1007  GO TO 1012
1008  IANT   =K+IAW
      IF (NOA-IANT) 1009,1010,1010
1009  IANT=IANT-NOA
1010  THE    =DELKP+ANOA*(IAW-1)
      IF (ABSF(THE)-90) 1012,1012,1011
1011  THE    =90
1012  COSTHE=COS(THE/CONRAD)
      AMP    =COSAMP*SIN(CONE1*COSTHE)
      PHI    =CONE2*COSTHE+WPH
      ARE(IANT)=ARE(IANT)+AMP*COS(PHI)
      AIM(IANT)=AIM(IANT)+AMP*SIN(PHI)
      PHIH(IANT,IWAVE)=PHI
      AMPH(IANT,IWAVE)=AMP
1013  CONTINUE
1014  CONTINUE
```

REDUCED PROGRAM LISTING NUMBER FOUR
TIME DEPENDENT PHASE SHIFT CALCULATIONS

```
      IF (T) 1190,1190,1160
1160  DO 1172 IWAVE=1,NWAVE
      IF (PSTEP(IWAVE)) 1161,1172,1161
1161  WPPH   =PSTEP(IWAVE)*T/SCANT
      DO 1170 IANT=1,NOA
      IF (AMPH(IANT,IWAVE)) 1169,1170,1169
1169  PA1    =PHIH(IANT,IWAVE)+WPHH(IWAVE)
      PA2    =PHIH(IANT,IWAVE)+WPPH
      ARE(IANT)=ARE(IANT)+AMPH(IANT,IWAVE)*(COS(PA2)-COS(PA1))
      AIM(IANT)=AIM(IANT)+AMPH(IANT,IWAVE)*(SIN(PA2)-SIN(PA1))
1170  CONTINUE
1171  WPHH(IWAVE)=WPPH
1172  CONTINUE
1190  CONTINUE
```

REDUCED PROGRAM LISTING NUMBER FIVE
SCANNING ELEMENT AND SCANNING BANK VOLTAGE CALCUALTIONS

```
         KC     =(CENT-ANOA2)/ANOA+1
         CDEL   =(CENT-ANOA2)-ANOA*(KC-1)
         CDELP  =ANOA-CDEL
         CDELA  =CDEL /ANOA
         CDELAP=CDELP/ANOA
         IF (KC) 1194,1194,1195
   1194  KC     =NOA+KC
   1195  IF (KC-NOA) 1197,1197,1196
   1196  KC     =KC-NOA
   1197  DO 1220 IDIR=1,2
         SUMI   =0.0
         SUMR   =0.0
   1199  DO 1217 ISE=1,NAS2
         GO TO (1200,1204),IDIR
   1200  IL     =KC-ISE+1
         IR     =IL+1

*******************************************************
*       * NOISE SIGNAL CALCULATION FOR LEFT           *
*                                                     *
*******************************************************

         GO TO 1208
   1204  IL     =KC+ISE
         IR     =IL+1

*******************************************************
*       * NOISE SIGNAL CALCULATIONS FOR RIGHT         *
*                                                     *
*******************************************************

   1208  IF (IL)1209,1209,1210
   1209  IL     =NOA+IL
   1210  IF(IL-NOA) 1212,1212,1211
   1211  IL     =IL-NOA
   1212  IF (IR) 1213,1213,1214
   1213  IR     =NOA+IR
   1214  IF (IR-NOA) 1216,1216,1215
   1215  IR     =IR-NOA
   1216  CONTINUE
         SRE    =(AMS*ARE(IL)+ANREL)*CDELAP+(AMS*ARE(IR)+ANRER)*CDELA
         SIM    =(AMS*AIM(IL)+ANIML)*CDELAP+(AMS*AIM(IR)+ANIMR)*CDELA
         SUMI   =SUMI+SIM*COSP(ISE)-SRE*SINP(ISE)
         SUMR   =SUMR+SIM*SINP(ISE)+SRE*COSP(ISE)
   1217  CONTINUE
         SUMRE(IDIR)=SUMR
         SUMIM(IDIR)=SUMI
   1220  CONTINUE
```

REDUCED PROGRAM LISTING NUMBER SIX

DETERMINATION OF THE NOISE SIGNAL VOLTAGE - FOR LEFT BANK

```
      IF (ISE-1) 1201,1201,1202
 1201 CALL RND(RN,RNDP)
      ANRERF=ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIMRF=ANOISJ*RNDP
      ANRER =ANRERF
      ANIMR =ANIMRF
      GO TO 1203
 1202 ANRER =ANREL
      ANIMR =ANIML
 1203 CALL RND(RN,RNDP)
      ANREL =ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIML =ANOISJ*RNDP
```

REDUCED PROGRAM LISTING NUMBER SEVEN

DETERMINATION OF THE NOISE SIGNAL VOLTAGE - FOR RIGTH BANK

```
      IF (ISE-1) 1205,1205,1206
 1205 ANREL =ANRERF
      ANIML =ANIMRF
      GO TO 1207
 1206 ANREL =ANRER
      ANIML =ANIMR
 1207 CALL RND(RN,RNDP)
      ANRER =ANOISJ*RNDP
      CALL RND(RN,RNDP)
      ANIMR =ANOISJ*RNDP
```

REDUCED PROGRAM LISTING NUMBER EIGHT
CALCULATION OF SYSTEM OUTPUTS

```
      SUMR  =SUMRE(1)+SUMRE(2)
      SUMI  =SUMIM(1)+SUMIM(2)
      DATAST=SQRT(SUMR**2+SUMI**2)

      SUMR  =SUMRE(2)-SUMRE(1)
      SUMI  =SUMIM(2)-SUMIM(1)
      DATADT=SQRT(SUMR**2+SUMI**2)

      ANGR  =ATAN2(SUMIM(2),SUMRE(2))*CONRAD
      ANGL  =ATAN2(SUMIM(1),SUMRE(1))*CONRAD
      DATP  =ANGR-ANGL
      IF (DATP+180) 1221,1221,1222
 1221 DATP  =DATP+360
      GO TO 1224
 1222 IF (DATP-180) 1224,1224,1223
 1223 DATP  =DATP-360
 1224 CONTINUE
```

APPENDIX C

SAMPLE INPUTS, FOR GCAAS, AND
HARD COPY OUTPUT

SAMPLE INPUT CONDITIONS FOR GCAAS

```
COL.
1   5   10        20        30        40        50        60          72
↓   ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓    ↓      ↓
    1    1    1
  120    145.50      6.00   48     20.00
    2    7.0000    5.0000    0.0000
    1.00    0.00   90.00    30.00   0.00
     .50   10.00   85.00    35.00  30.00
    0.0000    0
     90.00      2.00    2   30      2.00
```

THE HARD COPY OUTPUT FOR THESE SAMPLE INPUT CONDITIONS
IS CONTAINED IN THE FOLLOWING THREE PAGES OF THIS APPENDIX

SET NUMBER = 1000 * RUN NUMBER 1 OF 1 RUNS

ANTENNA ARRAY INFORMATION

NUMBER OF ANTENNAS = 120.00
DISTANCE FROM CENTER TO SCREEN = 145.50 METERS
DISTANCE FROM SCREEN TO ANTENNA = 6.00 METERS

SCANNER MODE

NUMBER OF SCANNING ANTENNAS = 48.00
COPHASAL ANGLE = 20.00 DEGREES

WAVE INFORMATION

CARRIER FREQUENCY = 7.00 MHZ
MODULATION FREQUENCY = 5.00 KHZ
PERCENT OF MODULATION = 0.00
NUMBER OF INCIDENT WAVEFRONTS = 2.00

WAVE NUMB	WAVE AMP	WAVE PHASE	WAVE AZM	WAVE ELEV	PHASE STEP
1	1.00	0.00	90.00	30.00	0.00
2	0.50	10.00	85.00	35.00	30.00

NOISE INFORMATION

STANDARD DEVATION = 0.00
RND STARTER = 0.00

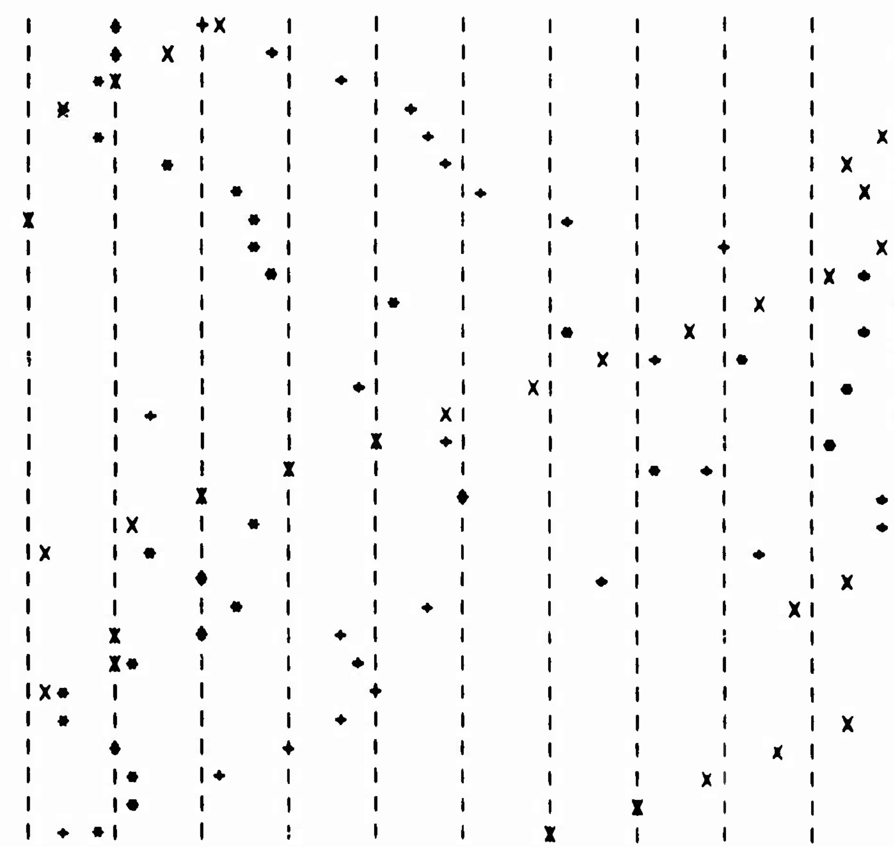
ANTENNA ARRAY SCAN SETTINGS

SECTOR CENTER = 90.00 DEGREES
NUMBER OF SCANS = 2.00
SCAN TIME = 2.00 SEC
NUMBER OF SAMPLE POINTS = 30.00
INCREMENT BETWEEN POINTS = 2.00 DEGREES

SET NUMBER = 1000 * RUN NUMBER 1 OF 1 RUNS
SCAN NUMBER = 1

MAX SUM DATA = 26.30
MAX DIF DATA = 17.89

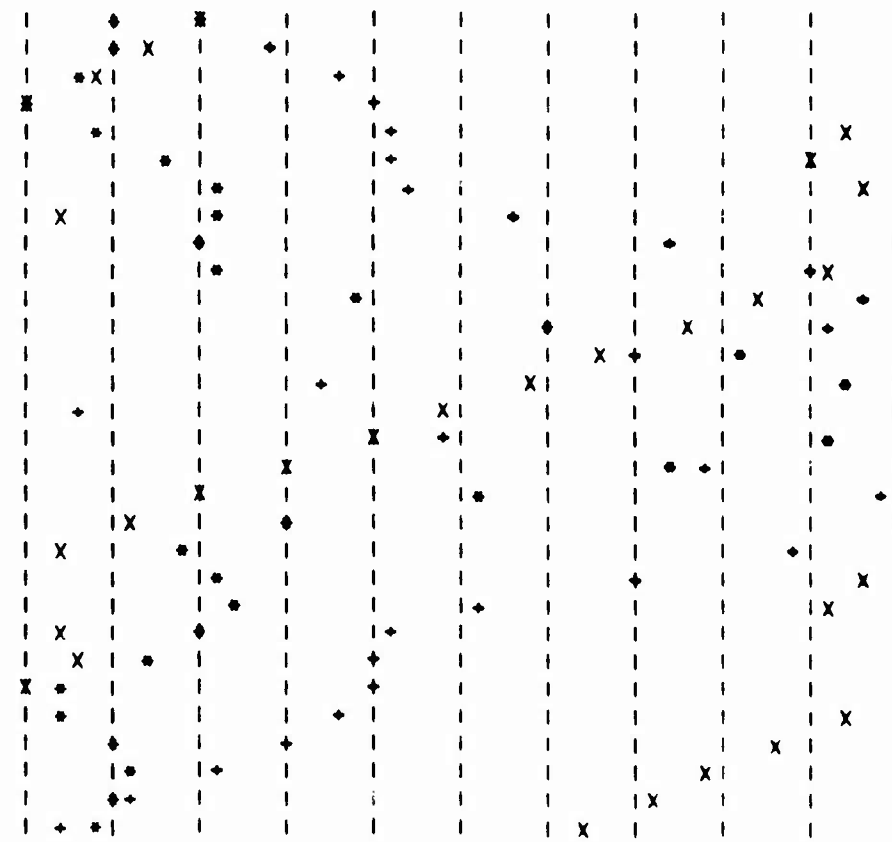
BORE SIGHT	SUM DATA	DIF DATA	PHASE DATA
61.00	2.87	3.43	-100.44
63.00	2.77	5.05	-123.30
65.00	2.14	6.60	-144.26
67.00	1.08	7.83	-167.76
69.00	2.24	8.32	170.13
71.00	4.41	8.69	155.60
73.00	6.27	9.40	162.53
75.00	6.74	11.26	-177.99
77.00	6.76	14.24	175.26
79.00	7.35	17.07	151.99
81.00	10.79	17.89	122.36
83.00	16.18	17.04	93.23
85.00	21.68	13.04	60.56
87.00	24.96	6.78	27.66
89.00	26.30	2.46	-5.07
91.00	24.11	8.70	-39.44
93.00	19.13	13.94	-72.17
95.00	13.07	17.41	-106.31
97.00	6.73	17.61	-140.26
99.00	3.64	15.16	-170.52
101.00	5.22	11.78	156.91
103.00	6.15	8.22	137.19
105.00	5.23	6.56	-144.88
107.00	3.40	6.79	-143.65
109.00	0.84	7.06	-171.63
111.00	1.26	6.51	160.65
113.00	2.81	5.43	129.57
115.00	3.30	3.81	99.73
117.00	2.91	2.23	72.14
119.00	2.11	0.78	34.77



SET NUMBER = 1000 * RUN NUMBER 1 OF 1 RUNS
SCAN NUMBER = 2

MAX SUM DATA = 27.52
MAX DIF DATA = 18.87

BORE SIGHT	SUM DATA	DIF DATA	PHASE DATA
61.00	2.82	3.69	-106.17
63.00	2.59	5.29	-130.69
65.00	1.80	6.72	-152.76
67.00	0.23	7.67	-177.02
69.00	2.10	7.79	160.34
71.00	4.25	7.88	145.73
73.00	5.87	8.41	165.17
75.00	5.93	10.62	-168.98
77.00	5.37	13.98	179.45
79.00	5.90	17.12	153.59
81.00	10.25	18.06	122.78
83.00	16.31	17.22	93.16
85.00	22.35	13.04	60.29
87.00	25.96	6.37	27.39
89.00	27.52	1.24	-5.15
91.00	25.41	9.09	-39.19
93.00	20.40	14.72	-71.46
95.00	14.32	18.49	-104.86
97.00	8.04	18.87	-137.74
99.00	4.86	16.52	-166.44
101.00	5.82	13.24	164.23
103.00	6.50	9.68	150.98
105.00	5.48	7.79	-166.67
107.00	3.63	7.62	-155.32
109.00	1.16	7.59	-177.38
111.00	1.36	6.88	157.90
113.00	2.85	5.71	129.34
115.00	3.33	4.03	102.17
117.00	2.91	2.41	78.09
119.00	2.07	0.94	47.83



APPENDIX D

LISTING OF PROGRAM SEGMENT OF TAPE HANDLING

```
M     NAME STHPS;
M     EQUIP=CARDRE,PRINTE;
M     SINGLE (AREA,DEAN);
C
C
C     PROGRAM:       STHPS
C     STANDING FOR: SAMPLE TAPE HANDLING PROGRAM SEGMENT
C
C     WRITTEN BY:    ROY F HUNNINGHAUS
C
C     WRITTEN FOR:  RADIOLOCATION RESEARCH LABORATORY
C                    DEPARTMENT OF ELECTRICAL ENGINEERING
C                    UNIVERSITY OF ILLINOIS
C
C     *******************************************************************
C
C     INPUT CARDS NECESSARY FOR OPERATION:
C
C     ONE PROGRAM OPERATION CARD:
C     (I5)     NSET    * NUMBER OF DATA SETS TO BE LOCATED
C     (I5)     ITAPE   * TAPE DRIVE NUMBER
C
C     THE FOLLOWING CARDS ARE NEEDED FOR EACH DATA SET TO BE LOCATED
C     DATA SET AND RUN NUMBER CARD:
C     (I10)    SETNUM * DATA SET REFERENCE NUMBER TO BE LOCATED
C     (I5)     IRUN   * DATA RUN REFERENCE NUMBER TO BE LOCATED
C
C     ************************
C
C     PLACE ANY ADDITIONAL INPUT CARDS FOR THE GIVEN DATA SET - RUN
C     AT THIS POINT
C
C     ************************
C
C     *******************************************************************
C
      DIMENSION AREA(500),DEAN(650)
C
      EH=4H   E
      HH=4H   H
      SH=4H   S
      DEAS=600
C
C
      READ 9000,NSET,ITAPE
C
      CALL SETRN(ITAPE,1)
      CALL FXBLK(ITAPE,1)
      CALL BLKLN(ITAPE,0,0)
C
      ISET=0
      GO TO 101
  100 CALL SETRN(ITAPE,1)
  101 ISET=ISET+1
      IF (NSET-ISET) 8500,102,102
  102 READ 9001,SETNUM,IRUN
      ASSIGN 8000 TO LAST
      GO TO 104
  103 CALL CLOSE(DEAN)
      CALL SETFD(DEAN)
  104 CALL OPEN(DEAN,DEAS,ITAPE,0,4HSIMU)
```

```
      CALL RDLR(DFAN,AREA,LAST)
C
  105 IF (AREA(2)-SETNUM) 103,107,103
C
  106 PRINT 9050,SETNUM
C
  107 NRUN=AREA(4)
      IF (NRUN-IRUN) 108,111,111
C
  108 PRINT 9051,SETNUM,IRUN,NRUN
  109 CALL CLOSE(DFAN)
      GO TO 100
C
  110 CALL RDLR(DFAN,AREA,LAST)
  111 IF (IRUN-AREA(3)) 110,112,110
  112 CONTINUE
      PRINT 9049,SETNUM,IRUN
      ISCAN=AREA(17)
      ISAM =AREA(19)
C
C     ***********************
C
C     PLACE ALL OPERATIONS FOR THE INPUT INFORMATION AT THIS POINT
C
C
C
C     ***********************
C
      DO 2999 IS=1,ISCAN
      CALL RDLR(DFAN,AREA,LAST)
C
C     ***********************
C
C     PLACE ALL OPERATIONS FOR THE SCAN AT THIS POINT
C
C
C
C
C
C
C     ***********************
C
 2999 CONTINUE
C
C
      CALL CLOSE(DFAN)
      GO TO 100
C
 800  CALL CLOSE(DFAN)
      CALL SETRN(ITAPE,1)
      PRINT 9052
      CALL EXIT
C
 850  PRINT 9099
      CALL EXIT
C
C     ****************************************************************
C
C
 900  FORMAT (2I5)
 9001 FORMAT (I10,I5)
 9049 FORMAT (1H1/5X,12HSET NUMBER  ,I10/ 5X,12HRUN NUMBER  ,I3,6H FOUND
```

```
     1      )
 9050 FORMAT (1H1/5X,12HSET NUMBER  ,I10/ 5X,17HNOT FOUND ON TAPE    )
 9051 FORMAT (1H1/5X,12HSET NUMBER  ,I10/ 5X,12HRUN NUMBER (,
     1  42H( GREATER THAN NUMBER OF RUNS IN THE SET (,I3,1H)     )
 9052 FORMAT (//5X,28HTAPE OPERATION OR TAPE ERROR      )
 9099 FORMAT (1H1/5X,30HALL OPERATIONS COMPLETED - PROGRAM END     )
 9100 FORMAT (1H1/5X,12HSET NUMBER  ,I10,14H • RUN NUMBER ,I3,4H OF .
     1  I3, 5H RUNS)
C
C
      END
```

APPENDIX E

LISTING OF PROGRAM STRO

```
PAGE   001

H      NAME STRO;
H      EQUIP=CARDRE,PRINTF;
H      SINGLE (AREA,DFAN);
C
C
C      PROGRAM:        STRO
C      STANDING FOR:   SIMULATOR TAPE READ OUT
C
C      WRITTEN BY:     ROY F HUNNINGHAUS
C
C      WRITTEN FOR:    RADIOLOCATION RESEARCH LABORATORY
C                      DEPARTMENT OF ELECTRICAL ENGINEERING
C                      UNIVERSITY OF ILLINOIS
C
C      COMPLETED:      MAY, 1970
C      REVISED:        OCTOBER, 1970 - FOR NEW TAPE HANDLING PROCEDURES
C
C      ****************************************************************
C
C      INPUT CARDS NECESSARY FOR OPERATION:
C
C      ONE PROGRAM OPERATION CARD:
C      (I5)     ITAPE   * TAPE DRIVE NUMBER
C
C      ****************************************************************
C
C      DIMENSION ARRAYS
C
       DIMENSION ALINE(51),AMARK(11)
       DIMENSION AREA(410),DFAN(650)
C
C      SET OPERATION CONSTANTS
C
       EH=4H    F
       DFAS=600
C
C      READ PROGRAM OPERATION INFORMATION
C
       READ 9000,ITAPE
C
C      INITIALIZE LINE PRINTER
C
       DO 900 II=1,51
  900  ALINE(II)=0
       DO 901 II=1,11
  901  AMARK(II)=27
C
C      OPEN TAPE ON UNIT NO. ITAPE
C
       CALL SETRN(ITAPE,1)
       CALL FXBLK(ITAPE,1)
       CALL BLKLN(ITAPE,0,0)
       ASSIGN 4000 TO LAST
       GO TO 1001
C
C      ADVANCE TAPE AND PRINT OUTPUT DATA UNTIL TERMINAL FILE IS REACHED
C
 1000  CALL CLOSE(DFAN)
```

```
      CALL SETFD(DFAN)
 1001 CALL OPEN(DFAN,DFAS,ITAPE,0,4HSIMU)
      CALL RDLR(DFAN,AREA,LAST)
      IF (AREA(1)-EH) 1100,3000,1100
C
C     PRINT H RECORD INFORMATION
C
 1100 NRUN=AREA(4)
      GO TO 1102
 1101 CALL RDLR(DFAN,AREA,LAST)
 1102 NWAVE=AREA(13)
      IRUN=AREA(3)
      PRINT 9019,(AREA(II),II=2,4)
      PRINT 9020,(AREA(II),II=5,13)
      PRINT 9021
      KKK=21
      DO 1105 IWAVE=1,NWAVE
      KKK4=KKK+4
      PRINT 9022,IWAVE,(AREA(II),II=KKK,KKK4)
 1105 KKK=KKK+5
      PRINT 9023,(AREA(II),II=14,20)
      ISCAN=AREA(17)
      ISAM=AREA(19)
C
C     PRINT S RECORD INFORMATION FOR EACH SCAN IN THE DATA RUN
C
      DO 1260 IS=1,ISCAN
      CALL RDLR(DFAN,AREA,LAST)
 1200 PRINT 9019,(AREA(II),II=2,4)
      DATASM=AREA( 6)
      DATADM=AREA( 7)
      PRINT 9025,(AREA(II),II=5,7)
      PRINT 9026
      DO 1250 IP=1,ISAM
      III=(IP-1)*4+11
      CENT  =AREA(III  )
      DATAST=AREA(III+1)
      DATADT=AREA(III+2)
      DATAP =AREA(III+3)
      PRINT 9027,CENT,DATAST,DATADT,DATAP,(AMARK(II),II=1,11)
C
C     PREFORM OPERATIONS FOR LINE PRINTER PLOT
C
      I1=((DATASM/100+DATAST)/DATASM)*50+1
      I2=((DATADM/1000+DATADT)/DATADM)*50+1
      I3= ((DATAP+183.6)/360)*50+1
      ALINE(I1)=46
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I1)=0
      ALINE(I2)=44
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I2)=0
      ALINE(I3)=24
      PRINT 9030,(ALINE(II),II=1,51)
      ALINE(I3)=0
 1250 CONTINUE
 1260 CONTINUE
C
```

```
PAGE   003

C      GO BACK AND PRINT H RECORD INFORMATION FOR THE NEXT DATA RUN
C      IF LAST DATA RUN IN THE DATA SET HAS BEEN PRINTED, ADVANCE TAPE
C      TO NEXT DATA SET
C
       IF (NRUN-IRUN) 1000,1000,1101
C
C      TERMINAL FILE HAS BEEN REACHED, PRINT ALL DATA PRINTED STATEMENT
C
 3000  PRINT 9070
       GO TO 5000
C
C       END OF TAPE HAS BEEN REACHED, PRINT ERROR STATEMENT
C
 4000  PRINT 9060
       GO TO 5000
C
C      CLOSE AND REWIND TAPE AND EXIT PROGRAM
C
 5000  CALL CLOSE(DFAN)
       CALL SETPN(ITAPE,1)
       CALL EXIT
C
C      ******************************************************************
C
C      THE I/O FORMATS ARE AS FOLLOWS
C
 9000  FORMAT (I5)
 9010  FORMAT (1H1/5X,13HSET NUMBER = ,I10,14H * RUN NUMBER ,I3,4H OF ,
      1I3,5H RUNS)
 9020  FORMAT (                                        /5X,25HANTENNA ARRA
      1Y INFORMATION//  5X,20HNUMBER OF ANTENNAS =,17X,F6.2/5X,32HDISTANC
      2E FROM CENTER TO SCREEN =,5X,F6.2,7H METERS/  5X,33HDISTANCE FROM
      3SCREEN TO ANTENNA =,4X,F6.2,7H METERS//  5X,12HSCANNER MODE//
      45X,29HNUMBER OF SCANNING ANTENNAS =,8X,F6.2/ 5X,16HCOPHASAL ANGLE
      5=,21X,F6.2,8H DERGEES// 5X,16HWAVE INFORMATION// 5X,19HCARRIER FRE
      6QUENCY =,18X,F6.2,4H MHZ/ 5X,22HMODULATION FREQUENCY =,15X,F6.2,4H
      7 KHZ/5X,23HPERCENT OF MODULATION =,14X,F6.2/   5X,31HNUMBER OF INC
      8IDENT WAVEFRONTS =,6X,F6.2/)
 9021  FORMAT (5X,4HWAVE,5X,4HWAVE,3(6X,4HWAVE),6X,5HPHASE/5X,4HNUMB,5X,
      13HAMP,7X,5HPHASE,5X,3HAZM,7X,4HELEV,6X,4HSTEP/)
 9022  FORMAT (5X,I3,1X,5(4X,F6.2))
 9023  FORMAT (/5X,17HNOISE INFORMATION// 5X,19HSTANDARD DEVATION =,18X,F
      16.2               / 5X,13HRND STARTER =,24X,F6.2// 5X,27HANTENNA ARRAY
      2 SCAN SETTINGS//5X,15HSECTOR CENTER =,22X,F6.2,8H DEGREES/
      3 5X,18HNUMBER OF SCANS = ,19X,F6.2/                          5X ,15HS
      4CAN TIME =     ,22X,F6.2,8H SEC     / 5X,25HNUMBER OF SAMPLE POINTS
      5=,12X,F6.2/ 5X,26HINCREMENT BETWEEN POINTS =,11X,F6.2,8H DEGREES)
 9025  FORMAT (     5X,13HSCAN NUMBER =,I3// 5X,14HMAX SUM DATA =,2X,F8.2/
      15X,14HMAX DIF DATA =,2X,F8.2/)
 9026  FORMAT (/7X,4HBORE,7X,3HSUM,8X,3HDIF,8X,5HPHASE/ 7X,5HSIGHT,6X,4HD
      1ATA,2(7X,4HDATA)/)
 9027  FORMAT (2X,4(3X,F8.2),5X,A1.4,10(4X,A1.4))
 9030  FORMAT (1H+,50X,51A1.4)
 9060  FORMAT (1H1/5X,  36HTHE END OF THE TAPE HAS BEEN REACHED)
 9070  FORMAT (1H1/5X, 38HALL THE DATA ON THE TAPE HAS BEEN READ)
C
C      ******************************************************************
C

       END
```

DISTRIBUTION LIST

Defense Documentation Center
Cameron Station
Building 5, 5010 Duke Street
Alexandria, Virginia 22314

Chief of Naval Research (Code 427)
Department of the Navy
Arlington, Virginia 22217

Commanding Officer
Office of Naval Research Branch Office
219 S. Dearborn St.
Chicago, Illinois 60604

Director, Naval Research Laboratory
Washington, D. C. 20390
Attn: Technical Information Office
Code 2027

Asst. Sec. of Defense for Research
and Engineering
Information Office Library Branch
Washington 25, D. C.

Director, Naval Research Laboratory
Technical Information Officer
Washington 25, D. C.
Code: 2000

Commanding Officer ONR Branch Office
1030 East Green St.
Pasadena 1, California

Electronics Research Directorate
Air Force Cambridge Research Center
Lawrence G. Hanscom Field
Bedford, Massachusetts
Attn: Library

Office of Ordnance Research
Box CM, Duke Station
Durham, North Carolina

Technical Information Officer
Signal Corps Engineering Laboratory
Fort Monmouth, New Jersey

Director
National Science Foundation
Washington 25, D.C.

Director, National Bureau of Standards
Department of Commerce
Washington, D. C.

Chief, Bureau of Weapons
Department of the Navy
Washington 25, D.C.

Commander
Naval Air Development and Material Center
Johnsville, Pennsylvania

Librarian
U. S. Naval Electronics Laboratory
San Diego 52, California

Commanding Officer and Director
U. S. Naval Underwater Sound Laboratory
Fort Trumbell, New London, Connecticut

Librarian
U. S. Navy Post Graduate School
Monterey, California

Commander
U. S. Naval Air Missile Test Center
Pt. Mugu, California

Director
U. S. Naval Observatory
Washington, D. C.

Research Laboratory for Electronics
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Department of Physics
Columbia University
New York 27, New York

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps (Code AX)
Washington, D. C. 20380

Dr. M. Chodorow
Microwave Research Laboratory
Stanford University
Stanford, California

Dr. Samuel Silver
Space Sciences Laboratory
University of California
Berkeley, California 94720

National Security Agency
Division of Physical Sciences
Ft. George G. Meade, Maryland

Commanding Officer
ONR Branch Office
459 Summer Street
Boston 10, Massachusetts

Library, Boulder Laboratories
National Bureau of Standards
Boulder, Colorado

Joyce E. Lunde
Reference Librarian
The Dodge Library
Northeastern University
Boston 15, Massachusetts

Librarian-in-Charge
The University of Auckland
School of Engineering
Ardmore College Post Office
NEW ZEALAND

Director U. S. Naval Security Group
Attn: G-43
3801 Nebraska Avenue
Washington, D. C. 20390

Chief of Naval Operations (op 07)
Code op 347
Washington 25, D. C.

Chief of Naval Operations (op 07)
Code op 371C
Washington 25, D. C.

Rome Air Development Command
Code RAWED - Mr. V. Nardoza
Griffiss Air Force Base
Rome, New York

Commander
Operational Development Force
U. S. Naval Base
Norfolk 11, Virginia

Director, Central Intelligence Agency
OCR/DD/Publications
Washington, D. C. 20505

Director, U. S. Naval Research Laboratory
Attn: Code - 5630
Washington, D. C. 20390

Mr. William Fay
Code S 220.2
Naval Electronics Laboratory Center
San Diego, California 92152

Naval Security Engineering Facility
Code 031
3801 Nebraska Avenue, North West
Washington, D. C. 20390

Major Donald Wipperman
ENASI - Griffiss AFB
Rome, New York

Leonard M. Posa
Science and Technology Division
Ft. George G. Meade
Maryland 20755

Prof. A. D. Bailey

Dr. E. C. Jordan

Mr. H. B. Lawler

ONR Res. Rep.

Prof. J. D. Dyson

Prof. P. Mayes

Prof. E. Ernst

W. Wood

E. Walton

L. J. Miller

J. Huff

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Department of Electrical Engineering University of Illinois Urbana, Illinois 61801	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
GENERALIZED DIGITAL SIMULATION OF A CDAA DIRECTION FINDING SYSTEM

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Technical Report No. 21

5. AUTHOR(S) *(Last name, first name, initial)*
Edward W. Ernst
R. E. Hunninghaus

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1970	75	3

8a. CONTRACT OR GRANT NO. N00014-67-A-0305-0002	9a. ORIGINATOR'S REPORT NUMBER(S) RRL Publication No. 382
b. PROJECT AND TASK NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	UILU-ENG-71-2539

10. AVAILABILITY/LIMITATION NOTICES
"EACH TRANSMITTAL OF THIS DOCUMENT OUTSIDE OF THE DEPARTMENT OF DEFENSE MUST HAVE PRIOR APPROVAL OF THE OFFICE OF NAVAL RESEARCH (CODE 427), WASHINGTON, D. C. 20360"

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research

13. ABSTRACT

The simulation program GCAAS (General Circular Antenna Array Simulator) has been developed to simulate the output data from a circularly disposed antenna array (CDAA)-direction finding system under known input signal conditions. The CDAA system which has been simulated is similar to the Wullenweber Direction Finding System at the University of Illinois and may consist of as many as 360 antenna elements in a circular array of any reasonable dimensions and simulates the outputs obtained from the array used in a scanning mode.

The input signal conditions may include up to five incoming signals at different azimuthal and elevation angles of arrival with time-dependent relative phase shifts between the incoming signals. The output consists of the sum, difference and differential phase data sampled at regular intervals of azimuth and stored on magnetic tape for further use in the determination of the direction of arrival. A maximum of 100 samples of the output data set may be obtained from each scan.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
CDAA Simulator						
Wullenweber Simulator						
CDAA						
Wullenweber						
Digital Simulation						
RDF System						
Wave Interference						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification